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JAMES D. MAHER
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REPORT

TO THE

Supreme Court of the United States

IN THE CAUSE

No. 1 ORIGINAL—OCTOBER TERM, 1914

The State of Georgia,
Complainant,
vs.
The Tennessee Copper Company and the Ducktown Sulphur, Copper & Iron Company, Limited.

On Motion to enter a final decree against the Ducktown Sulphur, Copper & Iron Company, Limited.

By JOHN T. McGILL, Inspector
NASHVILLE, TENNESSEE
January 1, 1916

ST. PAUL

BRANDON-NASHVILLE

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By JOHN T. McGILL, Inspector
Nashville, Tennessee
January 1, 1916

To the Honorable Supreme Court of the United States:

In obedience to a decree in this cause, I beg leave to submit the following report:

DECREE

On consideration of the motion of complainant for final injunction, the application of defendant Ducktown Sulphur, Copper & Iron Company, Limited, to show changed conditions, the proof submitted thereon, and of the argument of counsel thereupon had, and the Court being of opinion that by reducing the amount of sulphur discharged into the air said defendant probably can operate its plant without subjecting the territory of Georgia to serious danger of immediate injury, and deeming it desirable to be more fully informed concerning the true conditions and results which may be obtained by subduing the noxious gases discharged,

IT IS ACCORDINGLY ordered, adjudged and decreed:

(1) That the defendant Ducktown Sulphur, Copper & Iron Company, Limited, shall hereafter keep daily records showing fully and in detail the course and result of its operations.

(2) That Dr. John T. McGill, of Vanderbilt University, Nashville, Tennessee, is hereby appointed inspector to observe the operations of said defendant's plant and works. He shall be given by it at all times free and full access to its books, records and premises, and during the next six months he shall make frequent and careful observations—at least once each fortnight—of the conditions of the plant and works, the manner of their operation, the quantity and character of smoke emitted therefrom, and the resulting effect upon vege-

tation within the vicinity and in the State of Georgia. At the end of that time he shall make a full report of his observations accompanied by recommendations as to appropriate future action. To cover necessary cost and expenses incident to these services and the reasonable compensation of the Inspector, the defendant Ducktown Sulphur, Copper & Iron Company, Limited, is hereby directed to deposit with the Clerk of this Court, within ten days, the sum of five thousand dollars. Of this sum not exceeding two thousand dollars shall be paid from time to time, prior to October 12th next, by the Clerk to the Inspector, upon his written application, to cover costs, expenses, and on account of his services, etc.

(3) That said defendant hereafter shall not permit the escape into the air from its works of fumes carrying more than 45% of the sulphur contained in the green ore subjected to smelting.

(4) That it shall not hereafter permit to escape into the air of gases the total sulphur content on which shall exceed twenty tons during one day from April 10th to October 1st of each year or exceed forty tons in one day during any other season.

(5) That the cause will be retained upon the docket for such further action as may appear proper and either party may at any time hereafter apply for relief as it may be advised.

June 1, 1915.

(Signed) JAMES D. MAHER,
Clerk Supereme Court, U. S.

Scope of the Investigation

According to the decree the Court desires to be more fully informed concerning the true conditions and the results which may be obtained by subduing the noxious gases discharged; and the inspector is asked to report:

(1) The conditions of the plant and works.

(2) The manner of their operation.

(3) The quantity and character of the smoke emitted therefrom.

(4) The effect of the smoke upon vegetation within the vicinity and in the State of Georgia.

(5) Recommendations as to appropriate future action.

While it may be assumed that the report should include information or statements respecting each and every one of these specified subjects, it is not supposed that they are all considered of equal importance. For example, full and detailed information about the conditions of the plant and works would encumber the report with matter not germane to the questions at issue in the case; whereas the determination of the amount of sulphur in the escaping gases is of great importance, and it may be necessary to put on record numerous observations and state details in matters of procedure in order to inspire confidence in the results. But, as opinions will differ as to the relative importance of the various kinds of observations called for in the decree, it seems wiser to put into the report information that might be regarded as immaterial rather than risk omitting what might be considered essential.

The Plant and Works

The Company's plant and works consists of mines in Polk County, Tennessee, containing sulphur, copper and iron ores, and of the copper smelter at Isabella, Tennessee, with its accessories, the sulphuric acid plant and the reduction plant.

The Mines

There are three mines now open, the Mary mine, the East Tennessee mine, and the Isabella mine. The ores mined are essentially varying mixtures of pyrrhotite $Fe_7 S_8$ and chalcopyrite $Cu Fe S_2$. The number of tons of ore taken from these mines during 1914 and the first six months of 1915 and the percentage composition of the different ores are shown in table 1.

TABLE 1

1914

(First six months.)

	Ore	*Copper*	*Iron*	*Sulphur*
Mary mine	86255.1	2.19	28.27	19.33
East Tennessee mine	308.1	3.52	16.20	12.15
Isabella mine	1675.1	0.86	49.79	31.66

(Second six months.)

Mary mine	68888.9	2.32	32.86	21.46
East Tennessee mine	6504.6	2.79	15.22	10.62
Isabella mine	647.3	0.89	48.19	32.63

1915

(First six months)

Mary mine	75316.2			20.62
East Tennessee mine	9704.8			11.52
Isabella mine	828.1			31.84

The Smelter

The capacity of the smelter is from 600 to 700 tons of ore per day of twenty-four hours, with an output of 16,000 pounds of high grade matte assaying from 40 to 47% of copper. While operating under the decree of the Court, limiting the sulphur content of the escaping gases to not more than 20 tons per day, the charge of ore has been from 300 to 400 tons per day with an output of from 13,000 to 14,000 pounds of high grade matte.

There are two furnaces, No. 1 and No. 2, whose dimensions are length 32 feet, depth 11 feet, diameter at top 6 feet, at bottom 5 feet, with movable forehearth about 3 feet long, 3 feet wide and 2 feet deep. The lid, which can be raised by compressed air, fits into a groove in the rim of the furnace, and is attached to a truck which runs on a track lengthwise of the furnace. The lid and the bottom and walls of the furnace are jacketed, so that the furnace may be cooled by water on all sides. One hundred thousand gallons of water per hour run through the cooling jackets.

The Sulphuric Acid Plant

The sulphuric acid plant covers an area of two and one-third acres. Its capacity is as much as 160 tons per day of 60 degrees Baumé acid (77.67%); but the average production is about 135 tons under the usual conditions. From three to six tons of this acid is not shipped, but is used in the niter pots to form the nitrous fumes required in the chamber process of making sulphuric acid. From 5,000 to 7,000 pounds of sodium nitrate are used daily.

Its construction is that of a modern plant, modified

to adapt it to the manufacture of sulphuric acid by the chamber process from the gases emitted from a blast furnace in which sulphide ores are smelted. The dust chamber and flue system connecting it with the furnaces is more extensive than in the ordinary plant.

There are two large buildings, one for the Glover and Gay Lussac towers, the other for the acid chamber. Connecting these is the fan room, which contains besides the fans circulation tanks and acid eggs. To the east of these buildings are the storage tanks and the acid concentration building. The niter house and flue room adjoin the tower house on the north side. There is room in the tower house for additional Glover and Gay Lussac towers. The concrete foundation and the steel framework are already in place for three more Glovers and four more Gay Lussacs.

The Reduction Plant

The reduction plant consists of the bag house, figure 1, the furnace and condenser house, and the condensing chamber. Flues connect the bag house with the dust chamber and with the furnace, and a fan between the bag house and furnace gives the necessary draft.

The object of the reduction plant is to make elemental sulphur out of the sulphur dioxide of the smelter smoke.

There are many other subsidiary parts of the work,—the power house, blower house, machine shops, etc.—which need not be described.

The *conditions* at the smelter in so far as they relate to the investigation are developed under the discussion of the manner of operation and elsewhere in this report.

The Operation of the Plant and Works

Two branches of work are embraced in the company's operations,—the mining of the ores and the smelting of the ores, in each of which, under normal conditions, from two hundred to three hundred men are employed.

The Course of the Ore from Mine to Matte

The ore at the Mary and East Tennessee mines is taken at deep levels to shafts, raised to the surface by steam hoists, and conveyed to the bunkers of the smelter on the company's railway. The Isabella mine is near the smelter, and the ore is mined not much below the level of the smelter yard.

The ore of the East Tennessee mine contains the highest percentage of copper, that of the Isabella mine the lowest. The ore of the Isabella mine contains the highest percentage of iron, and that of the East Tennessee mine the lowest. On days when high grade matte is made, it is the custom to put into the charge a larger proportion of East Tennessee ore than on other days. Isabella ore is used at times to increase the proportion of iron in the slag, but it has of course also the effect of increasing the proportion of sulphur in the escaping gases.

The ores are delivered from the bunkers into the charging car and weighed on Fairbanks scales. Weighed amounts of silica and coke are added in such proportions as are required to form an easily fusible slag. The normal charge is about 7,000 pounds of ore mixed with from five to seven per cent of its weight of coke and a variable amount of silica.

The charge rests in the car on a horizontal belt which may be made to revolve over rollers at the rear and

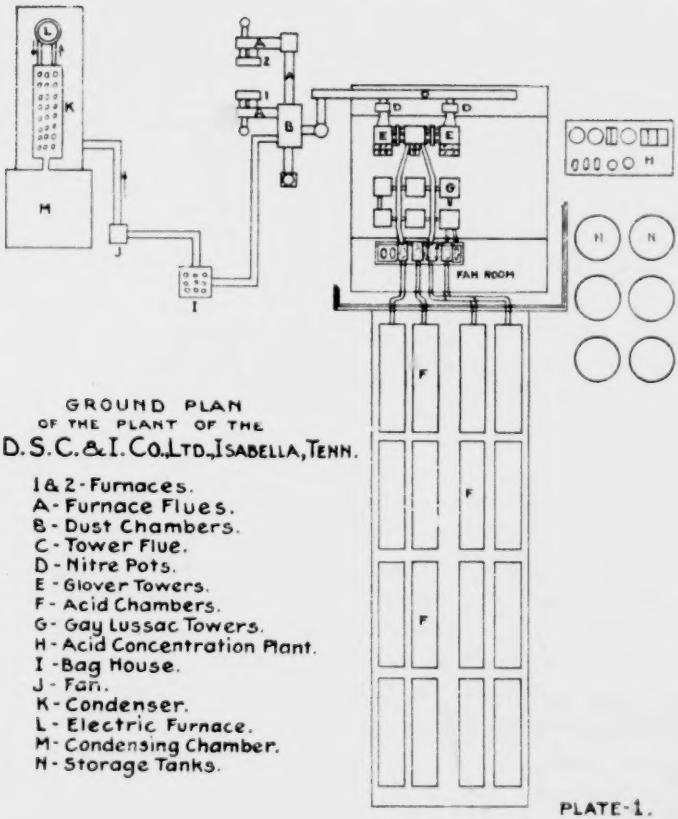
near the front of the car with a motion independent of that of the car. As the car traverses the length of the furnace, pushing or pulling the truck carrying the raised furnace lid, the charge is dropped at the end of the belt near the front of the car and distributed at the will of the smelter.

Only one furnace is operated at a time except for a short period when a change is made from one furnace to the other. The blast of about 80,000 cubic feet per ton of ore smelted enters the furnace through fifty-six tuyers, 3 inches in diameter, at atmospheric temperature, and a pressure of 20 to 30 ounces.

The Furnace Products and their Flow

The furnace products are the *matte*, the *slag*, and the *smoke* mixed with the residual air of the blast. The slag floating on the matte runs in a continuous stream from the forehearth. As it falls, a powerful current of water, issuing under pressure from pipes, strikes and granulates it. Two thousand gallons of water per ton are used. The granulated slag is raised by an endless chain of buckets and thrown into a bin, from which it is run into cars and dumped. A small portion of the slag takes the course of the low grade matte. The low grade matte, containing from 12 to 20% of copper and from 22 to 24.5% of sulphur, is withdrawn at intervals into ladles and poured out into open ground beds, where it solidifies on cooling. It is broken up, and about once a week it is smelted again in the furnace to produce high grade matte, which is cast into pigs and shipped. The high grade matte contains from 40 to 47% of copper and about 23.5% of sulphur.

The *smoke* contains three different kinds of material,



GROUND PLAN
OF THE PLANT OF THE
D.S.C.&I.CO.LTD., ISABELLA, TENN.

1&2 - Furnaces.
A - Furnace Flues.
B - Dust Chambers.
C - Tower Flue.
D - Nitre Pots.
E - Glover Towers.
F - Acid Chambers.
G - Gay Lussac Towers.
H - Acid Concentration Plant.
I - Bag House.
J - Fan.
K - Condenser.
L - Electric Furnace.
M - Condensing Chamber.
N - Storage Tanks.

PLATE-1.

—the flue dust, the fume, and the gas. The flue dust consists of solid particles of the charge thrown out of the furnace by the force of the blast. The fume consists of the vapors of substances formed in the combustion, which at ordinary temperatures are condensed to liquids or solids, but under certain conditions with exceeding slowness.

A variable portion of the smoke escapes from the furnace by leakage around the lid and during the charging. The remainder passes from the furnace into the furnace flue, where most of the flue dust and a portion of the fume are deposited, and then into a large brick dust chamber. From this the fume and gases are distributed (1) to the sulphuric acid plant by way of the circular tower and long flue, (2) to the reduction plant by way of the bag house, and (3) to the main stack. There is also an emergency stack, which connects with the furnace flue. The distribution is regulated by means of dampers.

(1) *The gases that enter the sulphuric acid plant* take the course usual in such plants, (See Plate 1) over the niter pots (D), into the Glover tower (E), through a fan to the acid chambers (F), through a fan to the Gay Lussac tower (G), and out the vent. The sulphur dioxide in them, which in the process is converted into sulphuric acid, is largely diluted with the nitrogen of the air that enters in the blast and is contaminated with deleterious products of the furnace, especially uncondensed fume and carbon dioxide. The fume is deposited as sludge in the settling tanks and acid chambers. The deleterious effects of carbon dioxide are obviated or counteracted by methods devised and precautions exercised by the manufacturers. The average composition of the gas before it enters the plant,

distinct from the fumes, is reported by the company to be sulphur dioxide 3 to 8%, carbon dioxide 3 to 11%, oxygen 0.5 to 11%, nitrogen in large quantities.

(2) *The smoke that leaves the dust chamber for the reduction plant* must be freed from fumes before the sulphur dioxide in it can be reduced to sulphur of high grade. This is accomplished in the bag house, where it passes into long woolen bags suspended from wires running across horizontally near the top of the house. The fume is retained in the bags by the meshes and is shaken out at intervals.

The gases are drawn by a fan from the bag house (See Plate 1) through a flue and passed into the condenser and furnace house, where they are conducted through a series of tubes in a large brick condenser, then into the furnace, up through the coke, heated to incandescence by an electric current. The reduction may be represented by the following reactions: $SO_2 + C = CO_2 + S$, $SO_2 + 2CO = 2CO_2 + S$. The vaporized sulphur passes from the furnace into the brick condenser mentioned above, pre-heating the gases passing through the tubes on their way to the furnace, and finally to the large condensing chamber.

The Quantity of Smoke Emitted from the Plant and Works

The quantity of smoke emitted from the plant and works is asked for in the decree of the court. The quantity of smoke could be determined readily if all the smoke came out through the stack and with some degree of regularity. This is not the case. A considerable amount of smoke escapes from the furnace

whenever it is charged,—and this happens more than a hundred times a day— and at the top around the lid there is a constant leakage which it is impossible to measure. The smoke from the stack varies greatly at different times of the day, the damper being raised or lowered to regulate the amount needed for the sulphuric acid factory. For these and other reasons no attempt was made to *measure the quantity of smoke* emitted from the works.

The volume of the blast being known, the quantity of gases coming from the furnace can be calculated from the analysis of the material of the charge of the slag, no change of volume occurring in the oxidation of the coke to carbon dioxide and the sulphur of the ore to sulphur dioxide. But while this problem is of interest and value for metallurgical purposes, its importance in this investigation did not seem sufficiently great to warrant an attempt at its solution. The volume of the gases coming from the furnace may be taken as somewhat less but approximately the same as that of the incoming blast. It was decided, therefore, to *measure the volume of the air issuing from the blowers.* For this purpose the company kindly consented to put in an air flow meter. Delay in shipment prevented its instalment before October. The result of its operation for twenty-three days shows an average flow of 27,300 feet per minute. The average flow on the 28th and 29th of October was 27,500 feet per minute. The green ore charge for those two days was 892 tons, and the total charge was 1,055 tons. This would give an average blast of 88,700 cubic feet per ton of green ore, or 76,000 cubic feet per ton of total charge. The number of observations however is too small for reliable results.

The Quantity of Sulphur Emitted from the Plant and Works

The quantity of smoke emitted is not of so much importance in this investigation as the quantity of *injurious gases*, particularly sulphur dioxide, in this smoke. A knowledge of the quantity of smoke would of course enable one to determine the quantity of sulphur dioxide by analysis. But as the quantity of smoke could not be determined accurately, another method was adopted to determine the quantity of sulphur dioxide. For convenience the statements are made in terms of sulphur, which is one-half by weight of the sulphur dioxide.

The amount of sulphur escaping into the air is taken as the difference between the amount of sulphur in the material put into the furnace and the amount in the matte, slag, flue dust, and acid recovered.

Daily Record; Furnace Charge Calculation

A daily record of these items, under the title "Furnace Charge Calculation," has been kept by the company since May 1, 1915, the day of this appointment, up to December 1. Sample copies of these daily reports are shown in Table 2.

The correctness of the conclusions as to the quantities of sulphur emitted depends upon the accuracy of those reports with respect to the items under the headings "material treated, lbs.," and "sulphur." Therefore, we have given these items careful attention.

The mines were visited and the sampling and weighing of the ores observed. The measurement and method of estimating the amount of acid made per day were

examined. Individual reports to the office for certain days were called for and the summation of the items verified. Daily duplicate samples of ore, matte, and slag were taken, and a number of samples of the sulphuric acid. Certain of these were sent away to chemists to check the analysis made in the company's laboratory and to determine whether the results obtained otherwise, as explained below, were correct.

TABLE 2

FURNACE CHARGE CALCULATION

June 6, 1915.

	Material Treated Lbs.	*Copper* %	Lbs.	*Iron* %	Lbs.	*Sulphur* %	Lbs.
Mary mine ore	595,287	2.37	14,108	31.40	186,920	19.28	114,771
E. Tenn. ore	195,228	3.72	7,262	14.55	28,405	10.08	19,679
Matte	27,160	15.94	4,329	49.00	13,308	24.55	6,668
Briquettes	13,500	2.22	300	21.31	2,877	12.85	1,735
Coke	50,400	.....	.....	.....	.....	.....	.....
Totals	881,575	.....	25,999	.....	231,510	.....	142,853
Matte	149,050	15.94	23,725	49.00	73,025	24.55	36,600
Slag	540,200	.24	1,296	27.60	149,092	2.45	13,505
Flue dust	44,079	2.22	978	21.31	9,393	12.85	5,664
Acid	278,000	.....	.....	.....	.....	25.40	70,612
Balance	.....	.....	.....	.....	.....	.....	16,472
Totals	.....	.....	25,999	.....	231,510	.....	142,853

FURNACE CHARGE CALCULATION

September 11, 1915.

Mary mine ore	689,040	2.36	16,261	33.20	228,761	20.27	139,668
E. Tenn. ore	114,840	6.45	7,407	22.70	26,068	16.27	18,684
Matte	34,650	11.82	4,095	51.75	17,931	24.75	8,576
Quartz	1,800	.....	.....	.....	.....	.....	.....
Coke	43,050	.....	.....	.....	.....	.....	.....
Totals	883,380	.....	27,763	.....	272,760	.....	166,928
Matte	211,750	11.82	25,029	51.75	109,520	24.75	52,410
Slag	529,500	.22	1,165	28.00	148,180	1.85	9,795
Flue dust	70,670	2.22	1,569	21.31	15,060	12.85	9,081
Acid	266,000	.....	.....	.....	.....	2.54	67,564
Balance	.....	.....	27,763	.....	272,760	.....	28,078

The company employs three chemists who make determination daily by analysis of copper, iron, silica, sulphur in ores, copper in matte, copper, iron and silica in slags. The iron and sulphur in matte are estimated in conformity with metallurgical practice elsewhere, from a diagram showing by means of curves the relation of the sulphur and iron to the copper in the matte. The flue dust is taken as 8% of the total charge and its content of sulphur established by a semi-annual analysis of a composite sample.

As the percentage of sulphur in slag is small, and its variation is of no practical consequence in the smelting of copper ores, it is determined like that of flue dust, by a semi-annual analysis. But in ascertaining the amount of sulphur in the escaping gases by the method now under consideration, this percentage becomes a factor of some importance on account of the great weight of slag. From June 1, 1915, to August 31, 1915, the percentage was taken as 2.45 in making up the daily record. A change was then made to 1.85 as the result of an analysis made by the company at the suggestion of the inspector. The company's records show that percentages ranging from 1.32 to 2.08 have been used during the last ten years. Analyses of six samples of slag, two of which were duplicates, made by the N. B. Pratt Company, of Atlanta, and W. E. Grainger, of Knoxville, give sulphur ranging from 0.96% to 1.42% with an average of 1.24%. Taking the daily average amount of slag as 300 tons, the company's estimate of sulphur escaping daily in the gases seems to be too low by 3.6 tons from June 1st to August 30th and 1.8 tons after August 30th. The company should however be allowed a credit of about six-tenths of a ton per day for sulphur lost in the sludge of the acid plant. This would

reduce the above figures to 3 tons and 1.2 tons respectively.

Analyses of the other materials gave figures in close accord with those used by the company in making up the record, including those for sulphur in the matte estimated by means of the curve.

The attention of the manager of the company was called to the fact that on some days the quantity of sulphur escaping in the gases exceeded the limit prescribed by the Court, and that this should be corrected or explained. The explanation was presented in a paper which it seems fair to the company to include in the inspector's report. (See Exhibit A, p. 61.)

Comments on the Company's Statement

The diagram gives a summation of three items of the daily furnace charge record for six months. A slight variation from the record may be noted in the sulphuric acid line, due to the fact that, instead of the total quantity formed, the net daily production was taken after deducting the three to six tons used in the niter box. This does not affect the line showing the quantity of escaping sulphur, as in getting the data for this the total daily production of acid was taken.

It seems evident that the company was not able to regulate accurately the amount of escaping sulphur, else it would have operated to its own advantage on a larger scale with an escape of between nineteen and twenty tons of sulphur instead of sixteen or seventeen tons, and without making itself liable to the charge of infringement of the Court's order.

The adjustments for successful operation are difficult, especially on a small scale with limitation as to the

amount of escaping sulphur. If the metallurgist uses ores rich in sulphur, more sulphur escapes; if poor in sulphur more coke must be added for fuel, thus forming more carbon dioxide, which retards the formation of sulphuric acid. On the small scale, the fuel, either sulphur or coke, must be proportionately greater, because the loss of heat from the furnace by radiation is not much less for the small charge than for the large. If the blast is increased in order to maintain the intensity of the heat, the gases that go to the acid plant are not so efficient for acid making because of increased dilution of the sulphur dioxide. If the heat is not sufficiently high, the contents of the furnace freeze. This happened twice during the summer.

The Ducktown Company and the Tennessee Company are the only ones known that make sulphuric acid as a by-product from the residual gases of a blast furnace copper smelter. The difficulties in manufacture have been overcome to such an extent as to make the process successful commercially where a market for the acid is near at hand, but the working of the Isabella plant is far from uniform. Only twice during the six months here considered has the full capacity of 160 tons per day been realized. The average number of tons of acid per day has been for June 108.4, July 129.6, August 110.5, September 113, October 127.4, November 113.5, giving an average per day for the six months of 118.4 tons.

The following summary, quantities reckoned in tons, has been made from the daily record from June 1, 1915, to December 1, 1915.

TABLE 3

Months	Green ore smelted	Sulphur in green ore	Acid made	Sulphur in acid	Per cent of sulphur Recov'd	Sulphur escaping	Per cent of sulphur Escap'g
June	9164.3	1598.3	3487.0	885.7	55.42	441.0	27.59
July	9910.1	1869.0	4018.1	1020.6	54.55	456.1	24.40
August	9444.3	1672.8	3421.3	869.7	57.99	508.4	30.39
September	10148.0	1898.6	3398.0	863.1	44.30	668.2	35.19
October	11732.4	2422.7	3949.3	1003.1	41.40	976.8	40.32
November	11308.2	2347.3	3405.5	875.4	37.29	1145.0	48.78
Per day 1st 4 mos.	316.93	67.94	117.41	29.82	51.70	17.00	29.46
Per day last 2 mos.	377.71	78.20	120.56	30.62	39.38	34.78	44.48
November only	376.94	78.24	113.52	29.18	37.29	38.17	48.78
Per day for 6 mos.	337.20	64.53	118.40	30.08	46.72	22.93	35.53

It appears from the above tabulated statement that reckoning the average amount of sulphur escaping per day in the gases for periods of one month, the limit of 20 tons was not exceeded in the first four months nor the limit of 40 tons in the last two months. If single days be considered, then the 20 ton limit was exceeded twenty-eight times in the 111 days from June 1st to September 20th, and the 40 ton limit six times in the 92 days it was allowable from September 20th to December 1st. The same explanations might be given of the transgressions in the latter period as have been offered for those of the former period.

Quantity of Sulphur Escaping Compared to that in the Green Ore

Let us now consider the quantity of escaping sulphur as shown in the above tabulated statement, with reference to that article of the Court's decree which reads, "That said defendant shall not hereafter permit the escape into the air from its works of fumes carrying more than 45% of the sulphur contained in the green ore subjected to smelting."

This is evidently not intended to apply to every single day, for on days when the furnace is run to make high grade matte the green ore constitutes but a small proportion of the charge, and the sulphur escaping, being derived largely from the low matte of the charge, may without exceeding the 20 or 40 ton limit in quantity be much above 45% of the green ore used in the smelting. Making the estimate by the month, it is found that the daily average for the first four months is 29.46%, for the whole six months 35.53%, for the last two months 44.48%, *for the month of November 48.78%*.

It may be said in behalf of the company that only on two days in November was the amount of escaping sulphur more than 40 tons, namely, November 10th, 47.96 tons, and November 21st, 40.12 tons. The daily record shows that the company was changing furnaces on November 10th. In doing this it is necessary to charge into the "blowing out" furnace a larger proportion of coke than usual. This increases the percentage of carbon dioxide in the furnace gases, which, retarding the formation of acid, allows more of the sulphur to escape into the air. The total amount of material charged into the furnaces that day was the largest of any day of the whole six months, yet the amount of sulphuric acid made was only 108 tons. The sulphuric acid plant seems to have not been working well in November. The average daily amount was 113.5 tons per day,—4.9 tons below the average of the other five months. Nevertheless, had the average in November been the same per day as during the other months, that is 119.43 tons, the percentage would have been 46.87%,—nearly 2% more than the limit.

The Character of the Smoke Emitted from the Plant and Works

The smoke issuing from the furnace contains, as has been stated elsewhere, flue dust, fume and gases.

Flue Dust and Fume

One may get an idea of the nature of the flue dust and fume from the following approximate analyses, the first four of which have been reduced to similar terms for the sake of comparison: No. 1 is flue dust from a green ore charge, No. 2 flue dust from a matte charge, No. 3 fume from the bag house, and No. 4 sludge (baked) from the acid chamber. No. 5 and No. 6 are the same analyses as No. 3 and No. 4, respectively, with the elements combined in the way the chemist considers most probable.

TABLE 4

	1*	2	3	4	5	6
Water					15 84	16 14
Insoluble					0 54	1 45
Zinc total	6 61	4 53	33 00	28 60		
Zinc Oxide					4 86	0 25
Zinc Sulphide					19 36	1 79
Zinc Sulphate					39 75	67 65
Sulphur (total)	12 82	10 88	18 98	15 64		
Sulphur (free)					3 20	a trace
Sulphuric Acid						0 70
Lead			7 45	a trace		
Lead Sulphide					8 60	
Lead Sulphate						a trace
Aluminum Oxide	4 58	3 87	1 24	0 77	0 71	0 36
Aluminum Sulphate					0 74	0 59
Iron Oxide	30 86	21 86	0 40	0 84	0 17	0 56
Iron Sulphate					0 49	0 64
Silica	29 55	25 23				
Calcium Oxide	6 43	6 73				
Magnesium Oxide	3 40	3 81				
Copper	2 22	3 00				

*Carbon undetermined

Comparing these, it may be seen that particles of the charge, such as silica, lime, iron, copper and carbon, are blown over in the blast and that the zinc and lead compounds especially are carried away in the fumes, getting into the bag house and the aicd chamber. The white fumes from the stack are probably much like the bag house precipitate in composition, consisting largely of oxides and sulphates of zinc and lead in a very finely divided state, partially or wholly enveloped in vapor of water and mixed with the gases of the smoke. The smoke from the top of the furnace contains flue dust, fume, and gases, and, when the charge is first put in, a small amount of elemental sulphur. The flue dust is soon deposited; while the fume and gases are, like those from the stack, carried away by the wind.

Nature of the Gases Escaping

In order to determine the composition of the gases escaping, analyses were made at seven different stations.

1. *The Furnace.* Samples were obtained by introducing a one-inch pipe horizontally through a hole in the side of the furnace near the top, the furnace being closed, and drawing the gases for analysis by aspiration through the absorption solutions of the apparatus. The results of analysis varied according to the time the sample was taken relative to the charging of the furnace.

Analyses made immediately after charging show a higher relative percentage of carbon dioxide and oxygen; those made some time after charging, a greater percentage of sulphur dioxide.

2. *The Furnace Flue.* The samples were taken near the entrance of the gases to the dust chamber. The results here are affected by irregularities in charging the furnace, the kind of charge, and the length of time after charging.

3. *The Dust Chamber.* The same factors as in the furnace flue affect the results, but not to the same extent.

4. *The Main Stack.* The samples were taken at a height of about 35 feet. The analyst attributes the higher percentage of oxygen and lower percentage of carbon monoxide and sulphur dioxide to the infiltration of air at the damper. The volume of smoke issuing from this stack at different periods of the twenty-four hours varies greatly on account of changes made in the position of the damper to meet the requirements of the sulphuric acid factory.

5. *The Emergency Stack.* The samples were taken at a height of about 30 feet. These analyses were made while this stack was used instead of the main stack after the "blowing in" of furnace No. 1 August 9th. The emergency stack is connected directly with the furnace flue.

6. *The Gay Lussac Tower.* The samples were taken from the exit stack a few feet above its junction with the tower.

7. *The Sulphuric Acid Concentration Plant.* The samples were taken from the exit stack of this plant.

8. *The Reduction Plant.* This plant was put in operation so late in the season that we were not able to get samples of the gaseous product for analysis. The company reports the presence of a large percentage of carbon dioxide, with only traces of sulphur dioxide.

For tabular statement of analyses and methods used see Exhibit B, p. 66.

In making up the report of analyses, no result has been included where there has been any reason to doubt its accuracy. Quite a number of analyses made and numbered consecutively are not given for various reasonable doubts as to correctness, but the original records of the analyses have been preserved.

The high temperatures registered in the analyses were taken with a Western Electric Company centigrade electric couple pyrometer. The taking of the temperature at the top of the furnace was overlooked at the time of getting the samples. One may get an idea of the temperature there at different periods from the following observations of September 14, 1915:

(1) Seven minutes after charging.....350 degrees C.
Nine minutes after charging.....225 degrees C.
Twelve minutes after charging.....675 degrees C.

(2) At time of charging.....675 degrees C.
Nine minutes after charging.....660 degrees C.
Twelve minutes after charging.....740 degrees C.

Certain irregularities in operation which might aid in accounting for variation in results are noted with the analyses.

The averages of the carbon dioxide and sulphur dioxide in six samples taken from the furnace, ten from the furnace flue, seventeen from the dust chamber, and four from the emergency stack are as follows:

Furnace.....Carbon dioxide, 8.50%; Sulphur dioxide, 4.40%
Furnace flue.....Carbon dioxide, 5.56%; Sulphur dioxide, 4.40%
Dust chamber.....Carbon dioxide, 6.56%; Sulphur dioxide, 6.10%
Emergency stack.....Carbon dioxide, 6.03%; Sulphur dioxide, 5.77%

Of these analyses, that of the sample from the dust

chamber probably most nearly represents the composition of the furnace gas with respect to these two constituents.

Sixteen analyses of the gas taken from the exit of the Gay Lussac tower gave an average of carbon dioxide 6.66%; sulphur dioxide, 0.27%; oxygen, 8.16%; and nitric oxide, 0.97%.

Inspecting these results, one may note with interest that the percentage of carbon dioxide is very nearly the same as was found in the dust chamber, that there is a considerable excess of oxygen—as might be expected from the abundant blast—that the sulphur dioxide has nearly all been eliminated from the furnace gas in making sulphuric acid, and that with the exception of two days there was no unusual loss of niter in the objectionable nitric oxide.

Not a sufficient number of analyses were made of the vapors given off at the concentration plant to warrant the drawing of inferences.

Effect of the Smoke Upon Vegetation Within the Vicinity and in the State of Georgia

The region here designated as within the vicinity and in the State of Georgia is practically conterminous with what, because of its characteristic topography, is generally known as the Ducktown Basin. A description of this basin with reference to the physical features that modify the diffusion of smoke and the relative position of important points seems appropriate here. Then may follow some account of how this condition was brought about and statements showing, first to what extent the Ducktown Company was responsible

and, second what the Company claims to have done during the last eight years to abate the nuisance with which it was charged.

The Ducktown Basin

What is known as the Ducktown Basin includes a territory in Polk county, Tennessee, and Fannin county, Georgia, approximately an ellipse in shape, with major axis about sixteen miles long, running south 20 degrees west, and minor axis of half that length. The basin has an elevation of from 1,600 to 1,700 feet, is cut by streams into narrow valleys 100 to 150 feet lower, and bordered by a rim of ridges and mountains 300 to 1,500 feet higher. (See photographs.) About one-third of the basin lies in Tennessee, mostly north of the Ocoee river, or Toccoa, as it is called in Georgia, which, running in the general direction of west 30 degrees north, enters Tennessee at Copper Hill somewhat to the east of the major axis of the ellipse. Fighting Town Creek, a large stream emptying into the Ocoee opposite the plant of the Tennessee Company, which is in Tennessee at the mouth of Mill Creek one-half mile down the river from Copper Hill, drains the southern portion of the basin. The creeks coming into the river from the north, naming them from the west, are Brush Creek, Potato Creek, Mill Creek, and Wolf Creek. (See Plate 2.)

Condition of Vegetation in the Basin

A part of the Ducktown Basin north of the Ocoee river, estimated at some ten or twelve square miles, is devoid of vegetation with the exception of sage grass and wild smilax that have taken root here and there,

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yards and gardens cultivated by a few of the residents, and several peach orchards; and the soil is badly eroded. The center of the barren region is somewhat south of the road from Isabella to Ducktown, not a great distance from where the roast sheds were once located.

Bordering this desert region is one covered with sage grass and vines and a few stunted shrubs and small trees, often with dead tops, that have survived. At some places numerous young maples are seen, but they are likely to be destroyed by fires starting in the sage grass in the fall or winter. Along the streams other grasses are found, and a more thrifty growth of trees on slopes and in hollows and coves somewhat sheltered from winds blowing from the central area. Dogwoods, sourwoods and blackgums constitute the principal growth in such places, and are especially noticeable in the late summer and in autumn because of the rich coloring their foliage assumes.

This almost treeless border extends on the east approximately to the North Carolina line, on the north to the top of the Stansbury mountain, on the west almost to the Little Frog mountain, and on the south from one to two miles into Georgia.

Out beyond this border the country for some distance is not heavily wooded. Most of the larger trees were cut down years ago, and sold to the Copper Company. The forest growth in a large part of this region does not appear thrifty. Trees with dead or dying tops seem more numerous than is usually seen under similar soil and climatic conditions elsewhere. Generally speaking, the area to which this description applies extends to the rim of the Ducktown Basin and perhaps even further in some directions.

Causes of Injury to Vegetation

The chief cause of injury to vegetation in the Ducktown Basin is generally admitted to be smoke emitted in the process of working the sulphureted ores of that region for copper. Before the organization of the Ducktown Company, the copper ores were smelted in charcoal reduction furnaces or worked by the leaching and precipitation process. Some of the timber was cut for making charcoal. The method used by the Ducktown Company for ten years after beginning operations in 1893 consisted in first roasting the ore in heaps between layers of wood in the open air and then smelting the roasted ore in a charcoal reduction furnace. The Pittsburgh Company adopted the same method in 1894, and this was continued by its successor, the Tennessee Copper Company. These roast sheds, as they were called, occupied acres of ground, and the wood required for firing them in the course of ten years practically exhausted the timber in the forest for miles around. The smoke from the burning wood and roasting ore formed a cloud so dense, old citizens say, that it was often difficult to find one's way through it. It must have gradually destroyed vegetation in the vicinity. Its area of destruction in the period of ten years was probably conterminous with the barren central zone described above. To complete the destroying work of the axe and the smoke, the rain is washing away the soil and leaving but furrowed hillsides almost beyond reclamation. (See photographs.)

Pyritic Smelting

About 1903 both companies began to prepare for smelting the green ore by the pyritic, or blast furnace,

process, and by the end of 1905 the open air roasting had ceased, and the latter process was in full operation. This eliminated the wood smoke and limited the escape of the smoke to the stack and the leakage from the furnace, but the amount of sulphur escaping into the air from the smelting of the ore in this manner was very slightly, if any, less than in treating the same amount of ore by roasting and charcoal smelting. The table below gives in the second column the number of tons of copper ore mined in Tennessee in the years annexed. The figures are taken from reports of the mining department of the State. The third column shows the number of tons of sulphur escaping into the air daily from the smelting of the ores, estimating the sulphur at 20% of the ore, for 1901, 1902, 1903, 1904 and at the recorded per cents of the Ducktown Company in the following years. The fourth and fifth columns are the same items as the second and third, but for the Ducktown Company alone.

TABLE 5

Years	*Tons of Ore*	*Tons of Sulphur escaping*	*Tons of Ore*	*Tons of Sulphur escaping*
1901	162,461	90.0	110,622	60.0
1902	335,864	184.0	127,613	70.0
1903	370,278	202.9	91,310	50.0
1904	384,886	216.9	138,524	75.9
1905	399,330	259.6	184,126	115.0
1906	538,141	303.5	189,506	147.6
1907	557,950	286.6	182,857	94.0
1908	618,806	303.0	167,183	70.0

Statistics for the Tennessee Copper Company are not at hand, but practically no copper ores were mined and smelted in Tennessee by any other than these two companies.

Complaint of Citizens and Injunction Proceedings

Comparing the figures for 1904, 1905, and 1906, it may be seen that soon after the change from the roasting to the pyritic method the scale of operation was largely increased, so that the quantity of gases or fumes escaping into the atmosphere was probably greater than ever before. Their sulphur content, estimated from the weight of the ore and the composition of the ore as used by the Ducktown Company, was above 250 tons a day. This condition incident to their operations was not satisfactory to the copper companies, for it subjected them to complaints of injury by citizens of the community in Tennessee and Georgia, and also it suffered a waste of material in the smoke, which should have been profitably utilized. Under like conditions in Europe, in several instances, high smoke stacks were erected with the purpose of saving vegetation from injury in the vicinity by preventing the smoke from reaching the surface of the earth, and at a distance by causing its dilution to such a degree as to render it harmless. In 1906 the Tennessee Company erected at Copper Hill a stack 325 feet high, that is about 175 feet higher than the general level of the higher ground in the Ducktown Basin. This, however, did not stop the complaint of the citizens. It was taken up by others farther away, until the State of Georgia, in behalf of its citizens, entered suit against both of the Companies and, May 13, 1907, the Supreme Court of the United States decreed that the State of Georgia in her sovereign capacity had the right of permanent injunction if she insisted upon her extreme rights. The State of Georgia, however, did not then insist

upon a final decree, but postponed action in order to allow defendants time to install certain appliances and apparatus which it was claimed by the defendants would eliminate the gases and fumes complained of from the atmosphere, thereby abating the nuisance.

In 1913 the State of Georgia entered into a stipulation with the Tennessee Company, granting a continuance of three years, but, failing to come to a similar agreement with the Ducktown Company, filed a motion for final injunction against this Company. The Ducktown Company claims that conditions have improved since 1907 and that no damage is now done to vegetation in Georgia by fumes or gases emitted in the operation of its plant. The Court has deferred final decision pending the ascertainment of the real conditions existing.

The policy of erecting a high smoke stack, which was adopted by the Tennessee Company in 1906, was not followed by the Ducktown Company. The main stack of their works rises only 90 feet above the smelter yard. Its top is a little below the summits of the hills nearby and 185 feet below that of the top of the Tennessee stack. It seems reasonable that a high stack offers better defense for the Tennessee Company one-half mile from the Georgia line and a low stack for the Ducktown Company two and six-tenths miles further away from Georgia. (See photographs.)

Experiments for Utilizing the Sulphur Dioxide of the Smoke

There is much to show that the Ducktown Company acted in good faith in an endeavor to install appliances and apparatus "to eliminate the fumes and gases com-

plained of," the grounds stated for the postponement from time to time by the State of Georgia of the motion for final decree. That the company looked to the utilization of the sulphur, as well as of the copper and iron of the ores, is indicated by the title adopted at the organization in 1891, "The Ducktown Sulphur, Copper & Iron Company, Ltd." The conversion of the sulphur dioxide of the smoke into sulphuric acid appeared to offer the best prospect for accomplishing this purpose. Preliminary experiments were made in 1905 and 1906 with the contact method of manufacturing sulphuric acid. A ten-ton plant was erected and the process tried in 1907 and 1908 at a cost of $60,000. This method of making sulphuric acid, which had been used successfully with gases richer in sulphur dioxide, was found to be impracticable with the gases issuing from the pyritic smelting of the copper ore of the Ducktown region. The contact plant was abandoned.

The chamber acid plant now used was erected in 1908 and 1909 at a cost of more than $500,000. It was put into operation in June, 1909. Improvements and enlargements up to the present time have added $100,000 to the cost. In the endeavor to convert a greater percentage of the ore into sulphuric acid, a McDougal roaster was erected and tried in 1913 and 1914. The cost of this was $20,000. It is no longer in use. At the same time as the roaster, the flotation method, now used successfully with zinc ores, was tried. Copper ores treated by this method can then be smelted, or they can be reduced by leaching or precipitation without the evolution of sulphur dioxide. The flotation plant, which was put in operation at a cost of $10,000, was destroyed by fire last September.

One of the most interesting experiments made by

the Company has for its object the utilization of the sulphur dioxide of the smelter fumes in the manufacture of elemental sulphur. This method, which involves the use of an electric furnace, was patented May 13, 1915, by W. F. Lamoreaux and C. W. Renwick. It was tried on a small scale in 1914. In the summer and fall of 1915 a plant was built which is calculated to make three tons of sulphur a day. It has been running almost continuously since the last of October. The cost has been nearly $30,000. It can be enlarged at a much smaller cost proportionately. Whether this venture will, like several others, be a failure or be used along with the sulphuric acid method or prove so successful as to replace the latter, is yet to be determined.

Is Vegetation Within the Vicinity and in the State of Georgia Injured by the Gases from the Ducktown Company's Plant as it is Now Operated?

Conditions have improved since 1907. The amount of ore smelted at that time by the Ducktown Company was as great as now, or greater. Then all of the sulphur in the gases emitted escaped into the atmosphere; now more than 50% of the sulphur in the gases is utilized in the manufacture of sulphuric acid. The company claims that the amount escaping now is so small that no injury is done to vegetation. The testimony of many witnesses goes to prove that injury is done; of many others, that it is not. The inspector has been asked to study the question and give an opinion.

How the Smoke Injures Plants

Since plants get nourishment both through the soil by means of their roots and through the atmosphere by means of their leaves, they might be starved or poisoned through either medium. The smoke, therefore, might be expected to injure plants either (1) indirectly by impoverishing or poisoning the soil about the roots, or (2) directly by attacking the leaves. Both the mineral constituents of the smoke in the fume and its oxides of sulphur in the gases are frequently brought down to the earth by the force of gravity or by rain and snow, and become components of the soil.

By referring to table 2, it may be seen that *the fume*, which is practically the same as the bag house precipitate, *consists principally of oxygen and sulphur compounds of zinc and lead*. It contains no arsenic. In this respect it differs greatly from the fume of copper smelters in the western states, which consist principally of lead compounds and arsenic. It is not probable that the soil in the Ducktown region is rendered materially less productive or injurious to vegetation by the minute quantity of zinc and lead compounds it acquires from the smoke. Very careful analyses made by the Selby Commission showed only doubtfully an increase in the percentage of lead in soil exposed to fume of much higher lead content than that of the Ducktown Sulphur Company's smelter.

The sulphur dioxide of the smoke comes into the soil as sulphurous acid or oxidized to sulphuric acid. The mineral bases of the soil combine with the acids to form salts—probably sulphates altogether. The soil of the Ducktown basin may contain a slightly greater percentage of sulphates than it did twenty-five years

ago, but these are not generally injurious to the soil; some of them are advantageous. If the soil should happen not to contain a sufficient amount of bases to neutralize the sulphuric acid, then any injury to the plant might be prevented at little cost by the addition of lime.

Sulphur Dioxide the Chief Cause of Injury

The chief injury to plants is generally conceded to come through the leaves by contact with the smoke. The constituents of the fume—the visible part of the smoke—are not the chief agents of injury. They are comparatively innocuous in the small quantities in which they exist in the highly diluted smoke. Leaves are not affected by a water extract of the fume containing many times as much of the soluble constituents of the smoke as is likely to be deposited on the leaves even in a dense smoke.

It has been established by investigations carried on in Germany for many years and by recent experiments in the United States that sulphur dioxide is the constituent of sulphuretted fumes most injurious to vegetation. When absorbed by the leaves of the plant it undergoes oxidation and is converted into a sulphate; yet the leaves are not so sensitive to sulphur trioxide fumes as to those of sulphur dioxide. Taking this into consideration and, in addition, the fact that analysis of the Ducktown smelter smoke shows no free sulphuric acid present, or scarcely any, no further account need be taken of sulphuric acid, and the question is narrowed to injury by sulphur dioxide in the smoke.

Smoke from Two Smelters

The solution of the problem is complicated by the fact that there are two smelters in this region and that during the period of this investigation the smoke from either furnace has probably at some time reached every locality in the Ducktown basin. The finding of injury by smoke entails the further question "Which smoke?"

The smelter of the Tennessee Company at Copper Hill is much the larger of the two; but this company claims (1) that a greater proportion of the sulphur is eliminated by its acid plant than is the case with the Ducktown company, (2) that the fumes issuing from its very high stack are so much diluted before they reach the ground that they are harmless to vegetation.

The smoke stack at the smelter of the Ducktown company does not quite reach to the level of the hills in the vicinity, so that this company claims that if any damage is done to vegetation it must be in the vicinity,—certainly not so far away as the State of Georgia.

The inspector had no authority to investigate the operation of the Tennessee Company's works and, consequently, the actual amount of the sulphur escaping in the gases emitted from these works being unknown, an inference could not be drawn by comparing the quantity of sulphur in the fumes escaping from the smelters of the two companies. It seemed that comparison might be made by determining separately the actual amount of sulphur dioxide present in the track of the smoke from these plants at various distances when the wind was blowing in such direction that there would be no doubt of the source of the smoke. It appeared desirable also that

PLATE III

1—Looking N. NE. from the hill E. SE. of the smelter: A—Potato Creek, B—Staff House, C—Capt. Nolde's residence, D—Stansbury Mountain.
2—Looking NW. from Staff House: A—East Tennessee mine, B—Little Frog Mountain—in the rim of the Basin, C—Capt. Nolde's residence.
3—Looking NW. A—Observing Station, B—Acid Plant.

daily observations be made of the trend of the smoke and the region it appeared to reach in order that it might be known in case of injury to vegetation in a certain locality, from which smelter the smoke was coming at the time the injury occurred.

The Observing Station

To facilitate work of this kind, a small tower was erected as an observing station on a hill at an elevation of 1785 feet, 600 yards, four degrees west of south from the smelter at Isabella and two and three-tenths miles from the smelter at Copper Hill.

The station was equipped with a weather vane, anemometer, barometer, thermometer, psychrometer, and the apparatus and chemicals needed for making sulphur dioxide determinations. The iron rod supporting the weather vane and anemometer above the roof passes down into the room and through the center of a table on which is a "Ducktown Special" topographical map adjusted to the points of the compass. Just above the map is a steel pointer running horizontally through the rod, fixed parallel to the vane and moving with it. With the two smelters as centers, circles were drawn on the map at one-fourth, one-half and one mile intervals, so that the distance and direction from the smelters of any point in the circumscribed area could be told at a glance.

From the observing station the plants of the Ducktown and Tennessee companies are both visible, and practically the whole Ducktown basin to the rim of mountains that surround it. The trend of the smoke from either smelter and its sweep could be seen for

miles, and points for making sulphur dioxide judiciously selected.

Because of engrossment of our time by other work and the difficulty of getting a competent and reliable man in the vicinity to make observations, the station was not used as much as anticipated. While a series of sulphur dioxide determinations there coincident with weather and smoke observations would have been useful, analyses made rapidly in the field at various points seemed preferable.

Method of Determining Sulphur Dioxide

Not a sufficient number of the factors and their relative influence are ever known to enable one to calculate the percentage of dioxide present in the atmosphere at a place on the surface of the earth whose elevation is known and its distance from the smelter from which the gas is coming. One may ascertain the percentage and quantity of the sulphur dioxide in the smelter smoke, its temperature and velocity as it issues from a stack of known height, the pressure, temperature, and humidity of the air, the velocity of the wind,—all of them factors great or small—yet find it impossible with these to solve the problem accurately. These aid in making an approximate estimate, but actual determinations chemically is the only means of getting reliable results.

Some time was spent in reading and experimenting in order to find a satisfactory method for determining very small amounts of sulphur dioxide in the atmosphere. The method finally adopted was the one used by the Selby Smelter Commission in an investigation carried on last year in Solano county, California, proof sheets

of which we had the privilege of seeing through the kindness of the Director of the Bureau of Mines, Washington, D. C. In this method the sample of air is collected in twenty-four liter bottles, partially evacuated by means of an air pump. The determination is made by means of $\frac{1}{100}$ normal solutions of iodine and sodium thiosulphate with a specially prepared starch solution as an indicator. This is checked by blank test with a similar bottle under exactly the same conditions, the color of the starch iodide in the two tests being brought to the same tint. We used ten-liter bottles and exhausted them to contain six liters of air, the number of inches of mercury necessary for each temperature and pressure being read from a calculated table on a card tacked near the barometric scale.

For reaching distant points quickly, an automobile was used with the steps strengthened and fitted with attachments so as to carry without jostling the boxes containing the apparatus for the sulphur dioxide determinations. Two sets of the apparatus in four boxes were carried, the air pump being on one of the boxes and used without removal. Everything necessary for the determination was enclosed in the boxes, and a sample could be taken and an analysis made in a few minutes.

Field Work in Sulphur Dioxide Determinations

Experiments were begun August 25th at the observing station, and in the field with the car August 27th, 1915. The work was extremely interesting to those engaged in it, and was carried on from day to day continuously whenever weather conditions appeared to

offer opportunity for obtaining data of value, and the records were made carefully, conscientiously, and as accurate as possible. From observations every morning a plan of operations for the day was made, the selection of locality depending upon weather conditions and the purpose in view. At first we planned to make determinations of sulphur dioxide for comparison at places when the smoke was coming from either smelter and again when it was coming from both; and we hoped to cover practically the whole field where the charge of smoke injury was made; but soon it was seen that this could not all be accomplished in the time at our disposal, so it was decided to make a point of determining the sulphur dioxide in as many samples as possible collected in the region between Isabella and Georgia at times when the wind was blowing the smoke from the Ducktown company's smelter toward Georgia. This would eliminate the smoke from the Tennessee Company's plant as a factor, provided the samples were not taken too soon after the wind had changed from a southerly to a northerly direction. A sufficient number of such analyses made at different distances from the source of smoke and under various conditions of wind and weather and sulphur dioxide output of the smelter ought to supply the necessary data for calculating the rate of diffusion and the degree of dilution of the gas at points within the vicinity and in the State of Georgia. Samples collected when the wind was in any direction except from the south, southeast, and southwest, might be used for the same purpose, provided care was taken to see that there was no admixture of the smoke from the two smelters. For comparison, the samples were taken whenever possible in

the midst of the cloud of smoke. In carrying out this plan of operation a sample would be taken near the smelter and then the car be run as rapidly as possible in the direction the smoke was going and successive analyses made as long as any sulphur dioxide could be detected in the air.

Sudden changes in the direction of the wind interfered greatly with the work. Often while we were preparing for an experiment in the midst of the smoke stream, the wind would veer and the smoke would be seen passing at some distance. Sometimes the results of analyses made at or near the same place and time will be found to differ considerably on this account—one sample having been taken in the smoke stream, the other at the margin or outside of it. Near the smelter when the wind is not strong and steady it may appear to blow at short intervals from various points of the compass because of temporary local currents and eddies.

Apparently another cause of difference in results of determinations nearly coincident, but of less consequence than sudden changes in the direction of the wind, is the variation in concentration due to waves of condensation and rarefaction in the smoke stream. This was especially noticeable in the smoke from the high stack of the plant at Copper Hill when seen from the observing station at right angles to the line of motion; and it was not unusual in the field for the men with the collecting bottles to wait for the coming of the denser smoke seen approaching.

What effect the topography of the country in the vicinity of Isabella has upon the density of the smoke issuing from the plant of the Ducktown Company has been much discussed. The opinion of the inspector

with reference to this question is based more on observation than experiment.

The smelter is situated at the junction of the narrow valleys of Potato Creek and Stewardtown Creek. The smoke stack does not rise to the level of the tops of the hills nearby; but ordinarily when the smoke is issuing freely from the stack it rises above the hills and moves over them without much obstruction. The smoke escaping from the top of the furnace, which much of the time during small output seems the greater quantity, comes out of the smelter shed more diffused than the stack smoke and has a tendency to drift along the valley running nearest the direction the wind is moving, i. e., northeast up Potato Creek, southeast up Stewardtown Creek, southwest down Potato Creek. In certain conditions of the atmosphere, e. g., during a fog, this is true of the smoke from the stack also. These statements must not be construed to imply that the smoke may flow down the narrow, crooked valley of Potato Creek and by reason of this channel be capable of doing injury to vegetation across the Ocoee river in Tennessee and Georgia. (See Plate 4.)

Several experiments will be found in table VI in which for comparison samples were taken simultaneously at the top and bottom of a hill toward which the smoke was coming or on a ridge and in a valley nearby, but the results in such cases depend so much on whether the smoke is coming from the furnace or the stack, the distance from the smelter, weather conditions, etc., that each experiment requires exact statement of the circumstances for trustworthy interpretation.

PLATE IV

1—Looking N. from the valley of Fightingtown Creek, showing the high stack of the Tennessee Copper Company plant.

2—Looking SW. from Staff House.

A—Staff House Bridge.
B—Ducktown Co. Ry.
C—Power House.
D—Steam Condenser.
E—The Ducktown Company's Plant.
F—Big Frog Mountain—in the rim of the Basin.
G—Shaft House, Burra Burra mine.

3—Looking East, The Ducktown Co. Plant: A—Acid House. B—Tower House. C—McDougal Roaster. D—Blower House. E—Main Stack. F—Emergency Stack. G—Cottrell Precipitation Plant. H—Transformer House. I—Bag House. K—Store and Office Building. L—Condenser and Electric Furnace House. M—Sulphur Condensing Chamber.

Explanation of Table 6

The original record contains the number of cubic centimeters of iodine used in the experiment and the temperature and pressure of the air at the time of making the determination. In a few of the experiments the humidity of the air was taken by a psychrometer. The direction and velocity of the wind were estimates generally, and may be considered only approximately correct. A "Ducktown Special" topographical map was used to ascertain location and get direction and distance from the Ducktown Company's smelter. These can be readily found by referring to the map—Plate 2. Fifty-three of the missing numbers are of experiments made in Tennessee and Georgia when the smoke was coming partly or wholly from the smelter of the Tennessee Company. The other numbers missing are those of experiments discarded, not because of apparent discrepant results, but because of something pertaining to them that threw doubt upon their correctness.

Under the heading Weather, S & C means "sun and cloud."

TABLE 6

DETERMINATION OF SULPHUR DIOXIDE IN THE ATMOSPHERE IN THE VICINITY OF THE DUCKTOWN COMPANY'S SMELTER.

A. Readings by C. B. Williamson, Jr., and J. B. Goodhue

August 25 to September 25, 1911

Test No.	Date	Time	Weather	Wind direction and velocity		Sulphur dioxide escaping fume	Parts per million	Location and Remarks (Distance reckoned from D. C. & C. Company's smelter.)
	Aug. 25					*Dr. 6*		
1		10:30	Hazy	E. NE	3		1.49	600 yds. S. at Observing Station.
2		4:00	Fair	E. NE	12		0.56	600 yds S. at Observing Station.
	Aug. 26					*Dr. 1*		
3		10:30	Fair	W. NW	5		0.07	Same place as above.
	Aug. 27					*Dr. 4*		
4		11:30	Cloudy	South	8		5.36	150 yds. N. Isabella mine, top of hill.
5		11:30	Cloudy	South	8		0.56	150 yds. N. Isabella mine, bottom of hill.

TABLE 6—*Cont'd*

Test No.	Date Time	Weather	Wind direction and velocity	Sulphur dioxide escaping tons	Parts per million	Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)
	Aug. 28			*12.5*		
12	9:35	Cloudy	N. of W 12		0.37	1800 yds. Stewardtown on hill above Angelico Rd. Odor slight.
13	9:56	Cloudy	N. of W 9		0.37	1650 yds. Angelico Rd. at turn to Bonnertown. No odor.
14	10:20	Cloudy	N. of W 14		0.00	2¼ mi. One-half mi. from Angelico Gap on Stewardtown Creek.
15	10:50	Cloudy	N. of W 14		0.37	400 yds. Forks of Copper Hill and Stewardtown Rd. at bridge. Slight odor.
16	11:15	Cloudy	West 14		0.37 5.86	400 yds. (1) On hill SE. of post office in edge of smoke. 400 yds. (2) In the smoke.
17	11:50	Cloudy	N. of W 13		0.37	600 yds. S. at Obs. Sta.
18	2:15	S. & C.	NW 13		335.00	On bunkers against wall of charging floor. Almost overcome by smoke in taking sample.
19	2:15	S. & C.	NW 13		35.5	100 feet further S. on bunkers than No. 18.
22	4:00	S. & C.	N. NW 10		0.93	1440 yds. SE. on Mineral Bluff Rd.
23	4:20	S. & C.	N. NW 6		0.19	300 yds. NW. on Ducktown Rd. on hill bet. Potato Creek and Burra Creek.
24	4:45	Hazy	N. NW 6		0.93	800 yds. on Copper Hill Rd. Slight odor.
25	5:30	Hazy	N. NW 8		0.56	1650 yds. on Copper Hill Rd. E. of Potato Creek.

NOTE.—This day very little smoke issued from D. S. C. I. plant as judged by the eye.

	Aug. 30			*21.3*		
26	9:15	Foggy	NE 6		0.38	2000 yds. at Staff-House, front yard towards smelter. No odor.
27	9:50	Cloudy	North 15		0.19	800 yds. S. of E. of Obs. Stat. on Copper Hill Rd. Odor slight.
28	10:00	S. & C.	North 15		2.47	800 yds. Same place as No. 27. Odor strong.
29	10:20	Clear	North 15		2.23	800 yds. Same place.
30	10:30	S. & C.	North 15		2.23	800 yds. Same location.
31	1:25	Cloudy	North 15		3.72	300 yds. S. of machine shop on hill. Matte charges to-day.
32	1:30	Cloudy	North 18		0.93	800 yds. SE. of Obs. Sta. on Copper Hill Road.
33	2:20	S. & C.	North 17		0.37	3700 yds. SE. one-fourth mi. from Quinn's orchard.
34	2:25	S. & C.	North 17		0.37	3700 yds. Same place.
35	2:45	S. & C.	North 15		0.19	3700 yds. Same place. Very slight odor.
36	2:45	S. & C.	North 15		0.19	3700 yds. Same place. Very slight odor.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Aug. 30			*21.2*		
37	3:30	Fair	North 13		0.37	2475 yds. One mi. N. of Coletown. Gas thick. Odor strong.
38	3:40	S. & C.	North 13		0.37	2775 yds. SW. of location of No. 37 on hill.
39	4:00	S. & C.	NW 15		0.00	2775 yds. SE. of No. 37, in valley in bed of creek about 300 yds. E. of N. of Belltown.
	Sept. 3			*20.0*		
62	1:30	S. & C.	E. of N 5		171.58	On bunkers close up to wall of charging floor.
62a	1:30	S. & C.	E. of N 5		73.75	100 feet further out on bunkers.
63	2:10	Fair	North 8		1.12	800 yds., 150 yds. E. of Obs. Sta. Smoke in the valley on E. side.
63a	2:10	Fair	North 8		0.00	Within a few feet of No. 63.
	Sept. 4			*21.7*		
68	9:35	Cloudy	NE 4		1.30	150 yds. W. of S. of smelter.
69	9:35	Cloudy	NE 4		1.30	200 yds. W. of S. of smelter.
70	9:40	Cloudy	NE 4		1.67	500 yds. down the hill from Obs. Sta.
70a	9:40	Cloudy	NE 4		3.63	500 yds. Smoke seemed high, yet showed amount on the ground.
71	9:50	Drizzling	North 6		5.77	300 yds. midway between smelter and Obs. Sta. Odor strong; smoke thick.
72	9:55	Drizzling	North 6		0.74	700 yds., 100 yds. SE. of Obs. Sta. Odor. Sample taken on edge of smoke column.
73	10:10	Drizzling	North 6		1.11	600 yds. at Obs. Sta. Odor strong in midst of smoke.
74	10:35	Drizzling	W. of N 6		0.74	1000 yds. at slag dump SE. of Obs. Sta. Column of smoke had just passed. Slight.
75	11:00	Drizzling	W. of N 4		0.18	800 yds. on Copper Hill Rd. midway bet. Obs. Sta. and slag dump toward Tenn. Co. plant. No odor. Smoke column had just passed.
76	11:35	Drizzling	North 5		0.37	2000 yds., one-half mi. from Mary mine toward Isabella on Copper Hill Rd. Slight odor possibly.

NOTE—This day smoke seemed to stick to the ground, although appearing in light clouds, small percentages of sulphur dioxide were found at a distance of over a mile from the D. S. C. I. furnace. There was no contamination of smoke from the Tennessee Company's smelter, as the wind was from a northerly direction and blew both smokes southerly, and no tests were made south of the Tennessee Company's plant.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 4			*21.7*		
77	11:35	Cloudy	North 7		0.28	2¼ mi. W. of S.
78	11:35	Cloudy	North 7		0.19	Same place.
	NOTE.—Nos. 77 and 78 were 500 yds. S. of Coletown in cove on road and on hilltop, respectively. No odor in either case, yet both in direct line of smoke and smoke could be seen passing.					
79	12:00	S. & C.	North 7		0.38	2¼ mi. South, one-half mi. SE. of Coletown on hill.
80	12:05	S. & C.	North 7		0.76	A few yds. from No. 79. Odor.
	Sept. 6			*21.3*		
89	9:00	Fog	Still		4.93	100 yds. E. by chemical laboratory. Strong irritating odor.
90	10:00	Fair	Still		2.42	100 yds. S. by garage opposite supply house. Substantial odor. Fog had practically cleared away except at distance.
91	10:20	Fair	Still		0.19	300 yds. in road bet. power plant of D. S. C. I. and Staff House. If anything, there was a slight breeze from north.
92	10:35	Fair	Still		4.88	150 yds. E. NE. by garage of D. S. C. I. east of chem. lab. If anything, slight breeze from W. Odor strong.
93	10:50	Fair	W. of S		0.00	1200 yds. beyond Stewardtown on Angelico Gap Rd. No odor.
94	11:00	Fair	SW 2		0.00	900 yds. NE. in rd. on bridge at foot of hill leading to Staff House. No odor.
95	11:40	Fair	SW 5		0.19	1200 yds. E. NE. on hill opposite Staff House across Potato Creek.
96	11:45	Fair	SW 6		1.12	500 yds. E. above post office on hill. Strong odor.
99	4:00	Fair	NW 5		6.32	500 yds. S. on hill at bridge on Copper Hill Rd. Smoke thick and odor strong.
	Sept. 6			*21.3*		
100	4:15	Fair	NW 5		1.30	Same location as No. 99 except in bed of branch.
101	4:50	Fair	North 5		0.00	800 yds. SW. on hill on Mineral Bluff Rd. Before test could be made smoke had shifted.
102	5:10	Fair	NW 5		4.28	400 yds. on hill above Stewardtown. Smoke had cleared away except that hanging close to ground. Odor moderately strong.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 7			*18.4*		
103	8:30	Foggy	NE 2		0.28	2000 yds. in front of courthouse at Ducktown; 12 liters of air used in this test.
104	9:30	Fog. sun	Still		0.56	1700 yds. on Ducktown Rd. Fog clearing away; 12 liters used.
105	9:45	Fog. sun	NE 2		2.50	400 yds. W. in valley. No odor. 12 liters used.
106	9:15	Fog. sun	NE 3		2.79	400 yds. W. on railroad in creek bed.
107	10:00	Fog. sun	NE 2		3.55	Same place. Wind very changeable.
108	10:15	Fog. sun	SW 3		2.05	200 yds. N. Odor slight. Wind blowing smoke apparently a little east of point taking sample.
109	10:25	Almost clear	SW 2		1.30	200 yds. NE. on Staff House Rd. Odor perceptible. Smoke seemed to be settling. Sun shining but fog still present.
110	10:40	Almost clear	SW 2		1.30	900 yds. on bridge at foot of Staff House hill. Odor slight.
111	10:55	Almost clear	SW 4		0.47	1100 yds. NE. front of Mr. Wallace's house in creek bed.
112	1:30	Clear	SW 4		0.00	100 yds. N. No odor. Wind too much E.
113	1:40	Clear	SW 5		0.00	200 yds. NE. Same conditions as No. 113. No odor.
	Sept. 8			*19.4*		
127	4:00	Clear	NW 8		1.21	1000 yds. in road 500 yds. SE. of Obs. Sta. Odor slight.
128	4:00	Clear	NW 8		1.30	Same location except on hill instead of in road.
129	4:30	Clear	North 7		2.23	100 yds. S. on Copper Hill Rd. Odor apparent.
	Sept. 9			*15.5*		
137	3:00	Clear	NE 8		0.36	100 yds. S. front of garage by supply house. Odor apparent. Very little smoke issuing from the plant.
	Sept. 10			*20.9*		
140a	8:15	Clear	SW 3		2.79	300 yds. NE. on bridge in Ducktown Rd. Odor apparent.
140b	8:15	Clear	SW 3		1.48	Same place, in valley below road in the creek. Odor apparent.
141a	8:35	Clear	SW 3		2.42	Same location as No. 140a.
141b	8:35	Clear	SW 3		1.86	Same location as 140b except on hill.
142a	9:05	Clear	SW 3		2.42	200 yds. NE. of smelter, beyond power plant. No odor.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 10			*20.9*		
142b	9:05	Clear...SW	3		1.86	Same location. No odor.
143a	10:00	Clear...SW	3		0.37	300 yds. on Copper Hill Rd., on bridge.
143b	10:00	Clear...SW	3		0.56	Same as 143a except on hill. Slight odor.
144a	10:20	Clear...SW	6		0.56	900 yds. at foot of Staff House hill on bridge.
144b	10:20	Clear...SW	6		1.48	Same location, except on hill.
145	10:35	Clear...SW	6		1.67	200 yds. between power plant and Staff House. Odor pronounced.
146	10:40	Clear...SW	5		10.79	100 yds. in road S. of post office, Isabella. Strong odor.
147	11:00	Clear...NW	8		1.30	800 yds. Stewardtown. No odor.
148a	12:00	Clear...NW	7		8.56	100 yds. from smelter by garage at chemical laboratory.
148b	12:00	Clear...NW	7		6.32	100 yds. from smelter on hill above post office. Strong odor at both.
149	12:15	Clear...NW	8		4.28	75 yds. near post office. Wind not quite direct from smelter.
150	2:15	S. & C..NW	8		348.28	On charging floor of the smelter. View befogged by smoke.
151a	3:15	S. & C..N. of W	8		2.05	200 yds. E. on top of hill beyond chemical laboratory.
151b	3:15	S. & C..N. of W	8		5.95	Half way up the hill.
152a	3:45	S. & C..N. of W	10		0.93	400 yds. on Potato Creek East, opposite Staff House Rd., near top of hill.
152b	3:45	S. & C..N. of W	10		3.72	30 yds. further down the hill. Strong odor here.
154	4:50	Clear...NW	10		1.42	800 yds. in Stewardtown.
155	5:10	Clear...North	8		0.56	1650 yds. S. or a little east of S. on branch. Slight odor.
	Sept. 11			*14.0*		
156	8:00	Fog.....E. of S. still			1.50	At the Staff House, north end by the steps. Thrown out on account of starch not acting properly.
157	8:35	Fog sun E. of S.	1		6.14	1100 yds. NE. of smelter, at Capt. Nolde's house. Strong odor and acrid taste. Strong odor had been observed at Staff House at 3 or 4 o'clock in the morning.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 11			*14.0*		
158	9:00	Fog.sun E. of S	1		4.09	1300 yds., 200 yds. further up valley than No. 157. Odor still persistent and acrid taste.

NOTE.—After making the last test we drove north on the Isabella Pack Gap road. On the way up smoke was observed to be passing close to the ground south, as if carried by an undercurrent. In the distance toward Stansbury Mt. the same phenomenon was observed. The wind overhead was distinctly northerly, and smoke from the D. S. C. I. smelter was traveling northerly, yet low down, as stated above, the smoke was moving southerly. This may account for the heavy odor at Staff House on foggy nights and mornings when the wind is S. of E., the smoke from either the D. S. C. I. or Tennessee Co. plant being banked against mountains and pulled backward by undercurrents.

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159	9:15	Clear...South	3		0.37	800 yds. Copper Hill Rd.

NOTE.—This is residual smoke from that travelling south mentioned in note following No. 158. The smoke was still travelling south and passed us before we could get apparatus fixed, although we drove well beyond the edge of it.

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160	9:35	Clear...SW	5		3.72	100 yds. N. on Ducktown Rd. at bridge. Very slight odor.
161	10:15	Clear...NE	5		3.72	100 yds. from smelter, by chemical laboratory. Smoke visible.
162	10:45	Clear...NE	8		3.35	200 yds. W. Very little smoke. Slight odor.
163	1:55	Clear...N. of W	10		9.60	100 yds. by garage opposite supply house.
164	2:30	Clear...N. of W	10		2.60	400 yds. Copper Hill Rd. Odor, but not strongest at time of taking sample.
165	2:50	Clear...N. of W	8		5.20	Same location as No. 164. Odor stronger.
166	3:20	Clear...NW	10		1.02	1000 yds. S. E. on hill, elevation 1,743 feet. Odor apparent.
167	3:55	Clear...North	11		0.47	1200 yds. on private road leading to "pest houses" near railway track, 200 yds. SW. of No. 166.
168	4:15	Clear...North	10		0.47	1200 yds., a little NW. of No. 167. Odor slight.
169	4:45	Clear...North	10		0.00	1650 yds. Almost directly S. or a little E. of S. No odor.
	Sept. 13			*22.0*		
170	9:30	Clear...SW	2		0.37	150 yds. NE. Smoke high (500 ft.). Slight odor.
171	10:00	Clear...SW			0.37	3300 yds. NE. on Potato Creek at foot of Mountain on crest of hill near Bald Mt. No odo
172	10:30	Clear...South.....			0.00	4100 yds. NE. foot of Stansbury Mt. on promontory.

NOTE.—This test should have shown gas if there was any lurking here, as on approach it is as if the gas were hanging here and had looked so for some time.

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TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 11			*14.0*		
173a	11:20	Cloudy	South.....		12.65	100 yds. N. across creek on Ducktown Rd.
173b	11:20	Cloudy	South.....		15.81	Same location. Gas high, but not so high as earlier.
174	12:00	Drizzling	South.....		3.81	200 yds. N. Strong odor.
175	1:00	Cloudy	NW 7		10.04	200 yds. S. On hill. Smoke dense.
176	1:25	Cloudy	N. of W 7		9.30	300 yds. on hill above Copper Hill Rd. Smoke dense.
177	1:45	Drizzling	NW 7		5.02	500 yds. SE. on ridge above Stewardtown. Smoke dense.
	Sept. 13			*22.0*		
178	2:20	Rain	S. of E 10		2.69	800 yds. NW. on Ducktown Rd. Smoke dense.
179	2:55	Cloudy	NW		0.00	This test shows nothing as gas had changed direction before taking sample.
181	5:00	Cloudy	SW 4		0.93	1600 yds. NW., SE. of Ducktown at Tennessee Co.'s tracks by bridge. Apparently not in direct line of smoke.

NOTE.—This day's work was run out in the attempt to get curve for a matte charge. During the day, on account of a "sow" in smelter, gases seemed denser than usual at the furnace. On account of the changeableness of the wind, it was very difficult to get the tests at consecutive and regular distances; and in the afternoon, on account of disarrangement of apparatus, one or two tests were lost.

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B. Readings made by Howard E. Palmer
September 18 to October 3, 1915

	Sept. 18			*18.0*		
1	8:15	Foggy	..Still.....		2.6	1100 yds. NE. at Staff House.
2	8:45	Fog lftg.	North1 or 2		1.8	Same place. Odor distinct in 1 and 2.
3	9:15	Clearing	North2 or 3		0.2	Same place. Odor very faint, if any.
4	9:45	Clear	...North3 or 4		0.0	Same place. No odor.
5	10:15	Clear	...North3 or 4		0.0	Same place. No odor.
	Sept. 21			*19.6*		
6	10:00	Clear	...N. NW 10		1.1	880 yds. SE. between Copper Hill Rd. and railroad. Odor fairly strong.
7	10:30	Clear	...N. NW 12		0.2	1300 yds. SE. on hill SE. of railroad track. Odor very faint, if any.
8	10:45	S. & C.	..N. NW. 10		0.0	1400 yds. S. SE. in valley. No odor.
9	11:05	S. & C.	..N. NW. 12		0.2	1300 yds. S. SE. on top of hill directly in line of smoke. Odor very faint, if any.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 21			*19.6*		
10	11:25	S. & C.	N. NW. 12		0.1	1300 yds. S. SE. Same place. Odor none.
10a	11:40	S. & C.	N. NW. 14		0.45	1500 yds. S. SE. Odor very faint.
11	2:05	Clear	N. NW. 15		0.1	2600 yds. S. SE. No odor.
12	3:25	Clear	N. NW. 15		0.0	2600 yds. S. SE. About 100 yds. S. of No. 11. No odor.
13	3:05	Clear	North 16		0.0	500 yds. S. on hill by Obs. Sta. No odor. Probably not in line of smoke.
14	3:30	Clear	North 16		0.9	700 yds. S. near Obs. Sta. Odor fairly strong.
15	4:30	Clear	North 16		0.9	900 yds. S. on Copper Hill Rd. Odor fairly strong.
16	5:00	Clear	North 14		1.5	Same place. Odor fairly strong.
	Sept. 23			*34.7*		
17	7:15	Fog clearing	S. SW. 1		1.5	1100 yds. NE. in valley N. of Staff House. Odor strong.
18	7:15	Fog clearing	S. SW. 1		0.75	1200 yds. NE. on hill 100 yds. NE. of Staff House.
19	9:30	Clear	E. SE. 3 or 4		3.7	250 yds. NW. on Ducktown Rd. Odor fairly strong.
20	10:25	Clear	S. SE. 2 or 3		0.0	2 mi. N. of Tenn. Copper Co.'s smelter in Ducktown Copper Hill Rd. No odor. Smoke high in the air.
	Sept. 27			*28.1*		
21	8:00	Thk. fog	SE. 2 or 3		2.4	1100 yds. NE. on road half way down hill from Staff House.
22	8:35	Fog&sun	Still.....		3.9	1800 yds. NW. in valley NE. of Ducktown E. of Tenn. R. R. track. Odor stronger than before.
23	9:05	Sun&fog	Still.....		3.3	3900 yds. NW. in valley where road from Boonville joins road from Ducktown to Stansbury.
24	9:35	Sun&fog	SE. 4 or 5		0.8	3¼ mi. NW. by N. in valley SE. of L. & N. Ry., one-half mi. S. of Stansbury.
25	10:00	S. & C.	SE. 4 or 5		0.8	4½ mi. N. in road at Zion Hill Church. Test somewhat doubtful.
26	10:25	S. & C.	NW. 6 or 7		0.0	5¼ mi. N. on same road. No odor.
27	10:45	Clear	NW. 5 or 6		0.0	4½ mi. Same place as No. 25.
28	11:00	S. & C.	NW. 3 or 4		0.0	3¼ mi. Same place as No. 24.
29	11:30	S. & C.	NW. 7 or 8		0.0	1800 yds. Same place as No. 22.

TABLE 6—*Cont'd*

Test No.	*Date Time*	*Weather*	*Wind direction and velocity*	*Sulphur dioxide escaping tons*	*Parts per million*	*Location and Remarks (Distance reckoned from D. S. C. I. Company's smelter.)*
	Sept. 28			*30.8*		
30	8:00	Fog clearing	Still.....		0.6	1800 yds. NW. in valley NE. of Ducktown just below the Tenn. Co. R.R.track.
31	8:25	Hazy	Still.....		2.05	1800 yds. N. on road along Burra Creek W, NW. of E. Tenn. mine. Odor fairly strong.
32	8:55	Hazy	Still.....		1.3	1½ mi. N. ¾ of a mi. E. of Boonville in valley of Creek near D. S. C. I. corn patch.
33	9:35	Hazy	Still.....		1.9	2¼ mi. NE. at forks where road running foot of Stansbury Mt. branches from road between Ducktown and Stansbury Gap.

NOTE.—Nos. 34, 35, and 36, at 10:05, 10:40, and 11:15, respectively, at points 3¼ mi. NE., 3 mi. NE. and 1800 yds. N. on Burra Creek showed only 0.1 parts sulphur dioxide. This amount is doubtful, as it represents only one drop of one-thousandth normal iodine.

	Oct. 1			*27.4*		
37	10:20	Cloudy	SW. W. 7 or 8		0.00	1¾ mi. E. NE. on road NE. by E. of Bonner town. Wind had shifted when sample was taken.
38	10:45	Cloudy	NW. 9 or 10		3.5	500 yds. NW. of Stewardtown. Odor strong.
39	12:20	Cloudy	W.NW.10to12		0.0	1600 yds. E. SE. on Angelico Gap Rd. Wind shifting, but seemed to be blowing direct from plant when sample was taken. No odor.
	Oct. 3			*38.9*		
40	7:00	Thk. fog	Still.....		1.2	1100 yds. NE., N. of Staff House. Odor fairly strong.
41	7:40	Thk. fog	Still.....		3.0	Same place. Odor strong.
42	8:15	Thk. fog	Still.....		2.5	1100 yds. NE. in valley below Staff House. Odor fairly strong.
43	8:40	Sun&fog	Still.....		2.8	1100 yds. NE. north of Staff House. Odor fairly strong.
44	9:00	Fog clrg	Still.....		3.5	Same place. Odor fairly strong.
45	9:30	Sun&fog	Still.....		3.1	Same place. Odor fairly strong.
46	10:00	Hazy	Still.....		1.5	Same place. Could not detect odor.
47	10:30	Hazy	Still.....		1.0	Same place. Smoke from plant rising straight up. No odor.
48	10:55	Hazy	NW. 1 or less		0.4	1100 yds. NE. in valley SE. of Staff House. No odor.
49	11:20	Hazy at E. distance	2 or 3		0.0	1100 yds. NE. north of Staff House. Odor none.

Discussion of the Sulphur Dioxide Determinations

A diagram showing graphically the quantity of sulphur dioxide found in the air at various distances from the D. S. C. I. Co. smelter on several days and at different hours of the day will aid in the interpretation of the results of the sulphur dioxide determinations. A line drawn to represent the mean or average of all the analyses would be not only inconclusive but misleading, for the reason that the proportion of sulphur dioxide in the air at any given time and place depends largely upon the direction and velocity of the wind. The resultant of a number of determinations would vary according to the ratio of the number of samples taken in the smoke stream to the number taken outside of it. This may be illustrated by drawing the line of one of the days, Plate V, Fig. 1, so as to include several or all of the cross-marked points outside of the smoke stream. The variation would not be so great, of course, at long as at short distances.

The curve A, Fig. 1, is drawn to show the greatest amount of sulphur dioxide found at any time at the various distances. Determinations during a fog are not included in this. The low point (No. 72) at 700 yards might well be omitted as it is the record of the only experiment made at that distance, and the analyst notes that the sample was taken "in the *edge* of the smoke column."

The most important feature of the curve is that it shows the rapid diffusion of the sulphur dioxide so that at a distance less than two miles from the smelter only 0.37 parts per million remains. The larger amount, 0.76, shown in one analysis at a distance of 2¼ miles was probably due to the fact that this sample

was collected on top of a hill about one mile from the plant of the Tennessee Company.

The experiments on September 10 were made under conditions about normal—20.9 tons of sulphur dioxide escaping from the smelter, fair weather, and the wind from five to ten miles an hour. At 1650 yards the amount of sulphur dioxide found was 0.56 parts per million.

It may be worth while for illustration to describe the work of September 11 more in detail.

In the morning there was a very damp fog so dense that objects could not be seen further away than about 400 feet. A very gentle wind from the southwest had brought the smoke up the valley from the smelter early in the morning with the fog. Mr. Williamson said that he had been smelling smoke since three or four o'clock that morning. The weather report shows that the wind was variable during the morning, veering to the north and northwest and rising to nine miles an hour in the afternoon.

An analysis at the staff house at 8:00 o'clock giving 1.5 parts sulphur dioxide per million was rejected because of some irregularity; one northwest of the staff house at Captain Nolde's in the valley gave 6.14 at 8:35; and one up the valley two hundred yards further away 4.09 at 9:00 o'clock. Williamson and Overstreet then went further to the northeast, but observing the smoke drifting in the other direction (see note with No. 158), they returned and worked in the vicinity of the smelter.

In the afternoon Overstreet and McGill followed the smoke to the southeast. When sample No. 164 was taken 400 yards from the smelter at 2:30, the wind

seemed to have shifted slightly, so a second analysis was made at 2:50 directly in the smoke, and this has been used in plotting the curve. As we went further out, the sulphur dioxide decreased, and at 1650 yards none was detected.

In more than one hundred determinations made during the period from August 25 to September 15, 1915, in no case when the weather was clear, was as much as one part of sulphur dioxide per million parts of air found beyond a distance of one mile from the D. S. C. I. Co. smelter.

The amount of sulphur dioxide found during clear weather at distances greater than one thousand yards from the smelter was so small, and especially when the wind was strong and the smoke was rising, that further experiments under these conditions seemed unnecessary. But the greater percentage of sulphur dioxide found in still, foggy weather, such as prevailed on the morning of September 11—shown in the fog line *d* of Plate V, Fig. 1—called for investigation. Therefore Dr. Palmer, who began taking observations September 18, was instructed to give particular attention to this phase of the question.

On September 27th he made determinations in the fog at the staff house, finding 2.4 parts per million at 8:00 a. m. 1100 yards from the smelter; then 3.9 parts at 8:35, 3.3 at 9:05, 0.8 at 9:35, northwest of the smelter at distances of 1, 1½, 2½, 3½ miles, respectively.

On September 28th in the fog nearly northwest of the smelter he found 0.6 parts at 8:00 a. m., 2.05 at 8:25, 1.3 at 8:55, 1.9 at 9:35, 0.1 at 10:05 at 1, 1, 1½, 2½ and 3½ miles, respectively.

Dr. Palmer says that on both of these days, at the

time when he made the last determination, "the sun had come out fairly bright and the wind had begun to blow somewhat, so that if any sulphur dioxide had been present there early in the morning, it might possibly have disappeared by the time the determinations were made." The disappearance of the sulphur dioxide as the sun comes out and the wind rises is illustrated by the experiments at the staff house on the mornings of September 18th and October 3rd, the results of which are shown graphically in Fig. 2, Plate V.

Reference to the weather report shows that the wind blew almost constantly from the southeast from the evening of September 26 to noon on the 28th, and very slowly except for three or four hours on the afternoon of the 27th. The weather conditions were such as in all probability added the effects of the smoke from the Tennessee Company plant to those of the smoke from the D. S. C. I. Co. smelter. One can not therefore reasonably hold the D. S. C. I. Co. wholly responsible for the 3.3 parts per million of sulphur dioxide in the air at a distance of 2¼ miles—the greatest amount found in our experiments that far away from the company's plant that possibly might be attributed to its smoke. Nevertheless we believe it probable that under certain weather conditions that much sulphur dioxide coming from the Ducktown Company's plant alone is sometimes present in the air at that distance.

The Least Amount of Sulphur Dioxide that Injures Vegetation

We were very desirous of determining by direct observation aided by chemical analysis the least

amount of sulphur dioxide in the smoke that would cause injury to plants under various atmospheric conditions. Many experiments have been made in Germany to ascertain this by passing sulphur dioxide over plants in glass cases; and the Selby Commission with the same end in view passed the gas over plats of barley growing in the field, varying the conditions in many ways. In both cases *sulphur dioxide mixed with air* was used. More satisfactory for the particular smoke problem would be the determination of the *amount of sulphur dioxide in the smoke* that injures the plant.

Captain Nolde lives near the west fork of Potato Creek 1100 or 1200 yards northeast of the D. S. C. I. Co. smelter. He has a great variety of flowers in his yard and garden. Leaves of some of the flowers, e. g., nasturtium, kudzu vine, and spider flower, were injured by the smoke of September 11, a sample of which taken near his residence gave an analysis 6.14 parts of sulphur dioxide per million parts of air. The injury was not severe. Many of the leaves of these plants escaped, and the leaves of many other plants were not injured at all. Under about the same conditions, several times previously, before we were prepared to make reliable analysis determining such small amounts of sulphur dioxide, somewhat severer injury had occurred to the leaves of plants at Mr. Nolde's and elsewhere in the vicinity. The extent of the injury varies with the length of time of contact, the number of applications, the state of the atmosphere, etc. Somewhat less than the amount mentioned above would probably injure the leaves of many plants in a moist atmosphere with frequent applications, or prolonged contact, and more would be required in a dry atmosphere.

Injury to Vegetation by the Ducktown Company's Smelter

In a dry atmosphere with variable wind not much injury is likely to occur more than a half mile away from the D. S. C. I. Co. smelter even with sulphur escaping in the highest amount that occurred during our investigation.

In the weather prevailing during the summer and fall of 1915, it is not probable that any visible injury was done to vegetation in Georgia by smoke from the Ducktown Company's smelter.

Within the vicinity of Isabella several times the leaves of plants were bitten as by a light frost, but the plants continued to grow and to put forth new leaves. Some leaf injury occurred at Ducktown. A large number of leaves on several trees observed was killed. Next spring the leaves will probably come out as usual; but it may be that the growth of the tree is retarded. We do not know whether the smoke came from the smelter of the Ducktown Company or the Tennessee Company. The smoke from either smelter occasionally reaches Ducktown.

Whether *within the vicinity* of the Ducktown Company's smelter, chronic or invisible injury is done to vegetation at the present time, we are not prepared to say. But having looked over the list of suits filed by individuals and corporations against the Ducktown Company and the location of the lands claimed to be damaged within the vicinity of the Ducktown Company's plant, we are of the opinion *that no visible injury of any consequence was done to vegetation on these lands by the smoke of the Ducktown Company's smelter during the period of our investigation.*

While engaged in the work incident to this investigation we devoted much time to the study of injury to plants by insects, fungi and smoke, and we have a collection of specimens showing leaf injury. We expected to discuss to some extent this phase of the subject in this report; but it seems unnecessary, and besides time is not now at our disposal to do so.

Recommendations as to Future Action

It is assumed that only recommendations would be appropriate that pertain to securing the operation of the company's plant in such a way as to guard against injury to persons and property within the vicinity and in that part of Georgia where complaint has been made.

In view of the fact that the degree of injury to vegetation by sulphur dioxide depends upon atmospheric conditions as well as upon the quantity of the gas present in the air, the inspector is of the opinion that the restriction of the company's operations during a *whole season* to an output far below its capacity is unnecessary; and that some means of regulating the quantity of sulphur escaping according to *the state of the weather* as well as by *the season of the year* might result in a larger aggregate output of manufactured products with, at the same time, less danger to vegetation within the vicinity.

The atmospheric conditions under which injury to vegetation is liable to occur are such as cause descent of the smoke while the wind is low and the humidity great. These conditions are readily recognized. The presence of sulphur dioxide is easily detected by its characteristic odor, and its quantity may be determined simply and quickly by chemical analysis. When danger to vegetation is indicated by the persistence of the above atmospheric conditions or the presence of a considerable quantity of sulphur dioxide in the air at some distance from the plant is shown by strong odor of the gas or by chem-

ical analysis, then the furnace charges and the blast should be changed so as to diminish the quantity of sulphur escaping.

It is therefore recommended

That the company be required to assign to some one the duties of watchfulness and precaution with respect to these things.

That the company be required to continue to keep a daily record such as that shown in table 2 of this report, open to inspection by the court or other authority, and also a weather record showing direction and velocity of wind at all hours of the day, and the humidity, temperature and pressure at certain intervals.

That, in ordinary conditions of the atmosphere, a total sulphur content of the gases escaping of not exceeding forty tons per day for two consecutive days during the period from May 1st to October 1st of each year be permitted, and not exceeding eighty tons per day for two consecutive days during the remaining months of the year.

That further restriction of the sulphur content of escaping gases be made for the same periods at times when unfavorable atmospheric conditions prevail.

That the present limitation of sulphur content of gases escaping to an amount not exceeding 45% of the green ore subjected to smelting be retained.

That the company be urged to enlarge the sulphuric acid plant or provide otherwise for disposing of a greater proportion of the sulphur dioxide in the gases emitted from the smelter.

That the company be urged to endeavor to lessen the leakage at the furnace and flues in order as far as possible to mitigate the unpleasant conditions about the plant due to the presence of the smoke.

Respectfully submitted,

JOHN T. MCGILL, *Inspector.*

CHARTS

TOO

LARGE

FOR

FILMING

(Exhibit A.)

Resume: Amount of Sulphur Output and Escape During the Six Months, May to October, Inclusive, 1915

The attached print shows graphically, by means of curves plotted daily from May 1st to October 31st, inclusive, 1915, the following data:

(a) Total number of pounds of sulphur entering furnace daily.

(b) Total number of pounds of sulphur escaping to atmosphere daily.

(c) Total number of tons 60 degrees Baume' acid produced daily.

The following data, tabulated in accordance with the above notation, represents approximately the normal operations of the Ducktown Sulphur, Copper & Iron Company, Limited's smelting plant prior to the rulings prescribed by the United States Supreme Court:

TABLE I

(Covering period from May 1st to 20th)

	(a)	(b)	(c)
Maximum	315,400 lbs.	137,800 lbs.	154.00 tons
Minimum	235,400 lbs.	63,200 lbs.	80.00 tons
Mean	275,400 lbs.	100,500 lbs.	117.00 tons
Average	270,480 lbs.	96,770 lbs.	130.80 tons

According to the decree above referred to, it is ruled that the defendant Ducktown Sulphur, Copper & Iron Co., Ltd., "shall not hereafter permit to escape into the air of gases the total sulphur content of which shall exceed twenty tons during one day from April 10th to October 1st of each year or exceed forty tons in one day during any other season."

Official notice of the decree was not received until May 20th, upon which date immediate action was taken to restrict smelting operations to comply with the prescribed rulings. Reference to the attached print will show that during the five days following (May 21st to 26th, inclusive) the most conscientious effort upon the part of the entire metallurgical staff failed to reduce the escaping sulphur to within twenty tons per diem. This failure was due to a combination of several causes,—principally the inexperience of the staff in operating the furnace under such reduced capacity as was necessitated and further by the inability of the mining department to mine and apportion ores of lower sulphur content. Following these five days of experimentation, the continuous average amount of sulphur escaping to the atmosphere was maintained well below the twenty ton limit, as is best shown by the following tabulation corresponding to that shown above in Table 1:

TABLE II

(May 21st to September 19th, inclusive)

	(*a*)	(*b*)	(*c*)
Maximum	199,700 lbs.	56,500 lbs.	160.00 tons
Minimum	92,200 lbs.	1,200 lbs.	54.00 tons
Mean	145,950 lbs.	28,850 lbs.	107.00 tons
Average	159,690 lbs.	32,690 lbs.	116.66 tons

It will be noted that while the average daily escape of sulphur amounted to only 16,345 tons, nevertheless upon several occasions the amount escaping exceeded twenty tons during one day, an explanation of which, in justice to the defendant, is deemed warrantable at this time.

With a given daily smelting capacity, the total amount of sulphur entering the furnace depends pri-

marily upon the amount of sulphur contained in the ores smelted. These ores vary widely in composition from day to day, since they are mined from numerous stopes or chambers in the mines, and it is very rare that on any two consecutive days the percentage of sulphur contained in these days' shipments will be the same. The result is that the smelter is called upon to make radical adjustments in the proportioning of the charges in order to maintain even approximately a uniform amount of sulphur entering the furnace. And not only does the sulphur content vary in an uncontrollable manner, but likewise the iron and copper content of the ores. This results in a varying composition of the matte and slag products of the furnace as well as the gases leaving the furnace top and over which the smelter has only a very limited control. Nor can the metallurgist compute the exact daily output of sulphur from the furnace until the day's work is done, and all assays of the resulting furnace products have been made and careful calculations worked out. It is true that the result of these computations are employed as a basis for the following day's operations, but meanwhile it will be found that the constituents entering the furnace have again changed in composition. It is evident, therefore, that no reliable means is available to predict *exactly* that a future day's operations will produce in the amount of sulphur escaping from the furnace.

The only rational method of recovering the sulphur from escaping furnace gases thus far adaptable upon a working scale is that of converting the sulphur dioxide into sulphuric acid. The defendant's acid plant has a normal average capacity of approximately 135 tons

acid per diem when treating gases of uniform composition. Any decrease in the percentage of SO_2 results in sluggish chemical reactions in the acid making process, so that production is correspondingly reduced.

Now, the total amount of sulphur escaping to the atmosphere is equal to the difference in the amounts of actual sulphur in the dioxide leaving the smelting furnace and that recovered by the acid plant in the form of sulphuric acid. As in the case of the smelter output, so it is in computing the acid production; i. e., there is no way of predetermining the acid production.

Considering the above conditions, it is at once evident that neither the smelter nor the acid maker can predict his respective output or recovery of sulphur in such manner as to maintain a uniform escape of sulphur to the atmosphere equal to any prescribed amount, say, twenty tons per diem; nor, indeed, to approximate closely any prescribed amount.

For these reasons, the defendant has been compelled to restrict its output to an amount greatly below the prescribed amount in order to conscientiously avoid any possibility of exceeding the limiting amount, and even so, this limit is occasionally exceeded.

During the period between September 20th and October 1st, by agreement between counsel for the State of Georgia and the defendant, permission was granted Dr. McGill to conduct experimentally daily increases in the amount of sulphur escaping to the atmosphere, such total escape, however, during any one day not to exceed forty (40) tons; the object of these experiments being to note the effect of such increased amounts of sulphur upon growing vegetation prior to the natural plant maturity and the possible effects of early frosts.

These experiments are evidenced by the gradual upward trend of the curve showing total amount of sulphur escaping to the atmosphere.

The sulphur output and recovery, also acid production, during the month of October, in accordance with the prescribed 40-ton limitation, are shown in the following annotated tabulations:

TABLE III

(October 1st to 31st, inclusive)

	(*a*)	(*b*)	(*c*)
Maximum	253,500 lbs.	85,600 lbs.	159.00 tons
Minimum	175,700 lbs.	38,900 lbs.	91.00 tons
Mean	214,600 lbs.	62,250 lbs.	121.32 tons

November 3, 1915.

(Exhibit B.)

TABLE 4

COMPOSITION OF SHELTER GASES

I. Gas from Furnace

Test No.	*Charge*	*Date*	*Hour*	*Carbon dioxide per cent*	*Oxygen per cent*	*Carbon monoxide per cent*	*Sulphur dioxide per cent*	*Temperature of gas*
69	Ore	Sept. 1	11 00	6.00	1.40	1.20	2.50	
72	Ore	Sept. 1	2.45	12.20	3.60	1.20	1.30	
78	Ore	Sept. 2	2.30	11.00	1.60	0.60	3.20	
83	Ore	Sept. 3	3.30	3.20	12.00	2.80	2.20	
84	Ore	Sept. 3	8.30	0.72	2.60	1.60	5.00	
85	Ore	Sept. 6	9.00	9.40	0.60	0.80	0.00	

NOTES

69. Taken ten minutes after charge, charging at 10-minute intervals.

72. Taken immediately after full charge was introduced.

78. Taken ten minutes after charge when charging at 12-minute intervals. Trouble with furnace operation due to chilling and low grade ores; iron scraps charged into furnace.

83. Charging on this day very irregular on account of broken scales, which made prompt weighing of charges difficult,—charging intervals ranging from four to twelve minutes. This charge made three minutes after a double charge. Scraps charged as needed to prevent chilling.

84. Sample taken one minute before charge was introduced. Old charge had been in only six minutes.

85. Charging regularly at ten-minute intervals.

2. Gas from Furnace Flue

Test No.	*Charge*	*Date*	*Hour*	*Carbon dioxide per cent*	*Oxygen per cent*	*Carbon monoxide per cent*	*Sulphur dioxide per cent*	*Temperature of gas*
33	Ore	Aug. 24	7.45	5.00	5.40		2.60	627° F.
34	Ore	Aug. 24	10.15	9.00	2.40	0.60	2.40	623° F.
36	Ore	Aug. 24	2.00	3.80	0.40	0.20	2.00	595° F.
42	Ore	Aug. 25	9.30	2.60	15.00	0.00	2.15	600° F.
52	Ore	Aug. 26	2.30	8.95	7.00	0.00	2.05	640° F.
64	Matte	Aug. 30	2.00	8.20	8.80	0.00	3.65	630° F.
65	Matte	Aug. 30	2.00	3.20	5.80	0.00		630° F.
74	Ore	Sept. 2	8.50	9.80	3.60	0.00	2.60	620° F.
76	Ore	Sept. 2	10.00	3.40	2.60	0.00	0.70	600° F.
81	Ore	Sept. 3	10.00	6.65	3.20	0.00	3.05	710° F.
82	Ore	Sept. 3	1.10	9.10	3.20	0.00	0.20	710° F.

1. Northern Hemisphere Counties

Row No.	County	Region	Mean	Median household income	Poverty rate	Unemployment rate	Population density
1	Ada	Sagebrush	51,204	47,890	14.2%	5.1%	312.4
2	Ada	Sagebrush	49,876	46,512	15.0%	5.4%	298.7
3	Ada	Sagebrush	52,310	48,045	13.8%	4.9%	325.1
4	Ada	Sagebrush	50,988	47,201	14.5%	5.2%	305.6
5	Ada	Sagebrush	53,402	49,330	13.1%	4.7%	341.2
6	Ada	Sagebrush	48,765	45,118	15.9%	5.8%	289.3
7	Ada	Sagebrush	50,144	46,902	14.7%	5.3%	310.8
8	Ada	Sagebrush	51,877	48,260	13.9%	5.0%	318.5
9	Ada	Sagebrush	49,530	45,774	15.4%	5.6%	295.0
10	Ada	Sagebrush	52,966	49,015	13.4%	4.8%	332.7
11	Ada	Sagebrush	50,421	46,688	14.8%	5.3%	307.9
12	Ada	Sagebrush	51,733	47,954	14.1%	5.1%	314.6
13	Ada	Sagebrush	49,288	45,530	15.6%	5.7%	291.4
14	Ada	Sagebrush	52,540	48,611	13.6%	4.9%	326.3
15	Ada	Sagebrush	50,702	46,975	14.6%	5.2%	303.8
16	Ada	Sagebrush	51,119	47,402	14.3%	5.2%	309.2
17	Ada	Sagebrush	49,655	45,902	15.2%	5.5%	297.6
18	Ada	Sagebrush	52,088	48,174	13.7%	4.9%	321.0
19	Ada	Sagebrush	50,266	46,441	14.9%	5.3%	300.5
20	Ada	Sagebrush	51,512	47,688	14.0%	5.1%	316.8
21	Ada	Sagebrush	49,902	46,150	15.1%	5.5%	294.2
22	Ada	Sagebrush	52,744	48,820	13.5%	4.8%	329.4
23	Ada	Sagebrush	50,533	46,760	14.7%	5.2%	306.1
24	Ada	Sagebrush	51,340	47,512	14.2%	5.1%	313.7
25	Ada	Sagebrush	49,777	46,025	15.3%	5.6%	299.8
26	Ada	Sagebrush	52,411	48,497	13.8%	4.9%	323.5
27	Ada	Sagebrush	50,399	46,633	14.8%	5.3%	304.0
28	Ada	Sagebrush	51,266	47,438	14.1%	5.1%	311.2
29	Ada	Sagebrush	49,841	46,088	15.2%	5.5%	296.7
30	Ada	Sagebrush	52,677	48,752	13.6%	4.8%	327.8

Notes.

(a) Sampling interval: 3 minutes. (b) Sample volume: 2 milliliters.

2. Southern Hemisphere Counties

Row No.	County	Region	Mean	Median household income	Poverty rate	Unemployment rate	Population density
31	Alpha	Tundra	41,208	38,560	18.4%	7.2%	41.6
32	Alpha	Tundra	42,015	39,330	17.6%	6.9%	44.2
33	Alpha	Tundra	40,772	38,104	18.9%	7.5%	39.8
34	Alpha	Tundra	41,530	38,911	18.1%	7.1%	42.5
35	Alpha	Tundra	42,284	39,602	17.3%	6.8%	45.1
36	Alpha	Tundra	40,955	38,277	18.7%	7.4%	40.3
37	Alpha	Tundra	41,762	39,118	17.9%	7.0%	43.0
38	Alpha	Tundra	42,540	39,845	17.1%	6.7%	46.0
39	Alpha	Tundra	41,098	38,433	18.5%	7.3%	40.9
40	Alpha	Tundra	41,871	39,214	17.8%	7.0%	43.6
41	Alpha	Tundra	42,396	39,720	17.2%	6.8%	45.7
42	Alpha	Tundra	41,334	38,690	18.2%	7.1%	42.1

Notes.

(a) Sampling interval: 3 minutes. (b) Sample volume: 2 milliliters.

Methods Used in Analysis of Gases at the Smelter

In making analysis of gases from the furnace, furnace flue, dust chamber and stacks, the *carbon dioxide*, *oxygen*, and *carbon monoxide* were determined by the use of Orsat's Apparatus, using potassium hydroxide (50 grams to 100 cc.) for the absorption of carbon dioxide; alkaline pyrogallol (containing 13.6 grams pyrogallol acid and 73 grams potassium hydroxide to 100 cc.) for the absorption of oxygen; alkaline or acid cuprous chloride for the absorption of carbon monoxide. *Sulphur dioxide* was determined by the Lunge-Reich Method, which consists in passing the measured gas through a known quantity of N 10 Iodine until the last drop produces a clearing of the blue color due to starch iodide. The excess is then neutralized by a few drops of Iodine necessary to reproduce the blue color. These two analyses were run simultaneously.

The per cent of sulphur dioxide was subtracted from the reading of the absorption by potassium hydroxide in the Orsat Apparatus (which represents both SO_2 and CO_2)—this gives per cent CO_2. The volumes of oxygen and carbon monoxide were read in their burettes as equal to their respective percentages since in this apparatus 100 cc. of sample are taken and measurement is before absorption.

In making analysis of the gases from the stack of the Gay Lussac tower the carbon dioxide, oxygen and carbon monoxide were determined in the Orsat Apparatus as described under "Analysis of Furnace Gases."

For sulphur dioxide the gas was passed through N 10 Iodine, a known volume of sodium thiosulphate N 10 added and the excess of permanganate titrated with N 10 ferrous sulphate.

In the method of absorption by KOH, the gas was passed through a wash bottle containing 200 cc N/10 KOH and another wash bottle containing H_2O, and the volume of the gas remaining was measured by measuring the volume of water displaced and correcting for temperature and pressure. The N/10 KOH and water were then diluted to a definite volume and an aliquot portion titrated with N/10 H_2SO_4, using methyl orange as indicator.

In the method of shaking with water, the sample of gas, generally about two liters in volume, was collected in a bottle over water by aspiration, leaving about 500 cc. of water in the bottle in which the gas was collected. This bottle was then shaken vigorously, and a definite portion of the solution diluted with N/10 KOH. The volume of gas collected was determined by measuring the volume of water displaced and correcting for temperature and pressure.

It is noted that the results by absorption in KOH are much higher than the results by absorption in H_2O, probably indicating incomplete absorption in the latter case.

Financial Statement

Receipts		$1,750.00
Disbursements		
Travel—Seven trips to Isabella, one to Atlanta, one to Washington, one to St. Louis, Mo., and Hillsboro, Ill.	$306.17	
Board	61.58	
Office expenses	12.67	
Supplies and transportation for investigations	507.39	
Salary of assistants	755.00	
Assistance in the field	118.97	
Labor	109.80	
Report	212.00	
		$2,083.58
Deficit		$ 333.58
Credit D. S. C. I	$ 10.00	
on R. R. tickets	23.40	
		33.40
Total deficit		$ 300.18

ACKNOWLEDGMENT

I wish to acknowledge my indebtedness first of all to Mr. Charles S. Williamson, Jr., Associate Professor of Industrial Chemistry in Tulane University. Most of the chemical work was done by him, and his counsel and coöperation were, I might say, almost indispensable. Mr. J. B. Overstreet, a graduate of the Alabama Polytechnic College, was prompt and efficient in the work assigned him. Dr. Howard E. Palmer, of the Bureau of Chemistry, Washington, D. C., whom the Chief of the Bureau, Dr. Carl Alsberg, kindly gave leave of absence for a month, did excellent service in continuing the work through the latter part of September and the first week in October.

I wish to express my thanks to Mr. C. W. Renwick, Manager, and Mr. W. F. Lamoreaux, Assistant Manager, for their kind treatment of myself and associates; and to say that they afforded us every facility for the investigation and ever expressed the desire that it be made as thorough as possible.

To Professor Samuel Bain, of the University of Tennessee, I am indebted for literature relating to injury to plants by insects, fungi, and sulphur dioxide, and to officials of the Bureau of Mines for proofs of the method used by the Selby Commission for the determination of sulphur dioxide.

JOHN T. MCGILL.

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No. 1, ORIGINAL

IN THE

Supreme Court of the United States

OCTOBER TERM, 1915

THE STATE OF GEORGIA, Plaintiff,

vs.

THE TENNESSEE COPPER COMPANY AND THE DUCKTOWN SULPHUR, COPPER & IRON COMPANY, LIMITED, Defendants

In Equity

APPLICATION OF DEFENDANT DUCKTOWN SULPHUR, COPPER & IRON COMPANY FOR A FINAL DECREE DISMISSING THE ORIGINAL BILL AS TO IT AND BRIEF AND ARGUMENT IN SUPPORT THEREOF

W. B. MILLER,
J. A. FOWLER,
Solicitors for Ducktown Sulphur, Copper & Iron Company, Limited.

STUDLEY PRINTING CO., KNOXVILLE

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To the Honorable The Supreme Court of the United States:

This defendant respectfully shows to the Court:

I.

At the October Term, 1914, after a hearing had been had on a motion of plaintiff for a final injunction and on application of the defendant Ducktown Sulphur, Copper & Iron Company, Limited, for permission to show changed conditions and for a final decree dismissing the original

bill as to it, the following order was entered by the Court:

"On consideration of the motion of complainant for final injunction, the application of defendant Ducktown Sulphur, Copper & Iron Company, Limited, to show changed conditions, the proof submitted thereon, and of the arguments of counsel thereupon had, and the Court being of opinion that by reducing the amount of sulphur discharged into the air said defendant probably can operate its plant without subjecting the territory of Georgia to serious danger of immediate injury, and deeming it desirable to be more fully informed concerning the true conditions and results which may be obtained by subduing the nuisance given discharged.

"IT IS ACCORDINGLY ordered, adjudged and decreed:

"(1) That the defendant Ducktown Sulphur, Copper & Iron Company, Limited, shall hereafter keep daily records showing fully and in detail the course and result of its operations.

"(2) That Dr. John T. McGill, of Vanderbilt University, Nashville, Tennessee, is hereby appointed inspector to observe the operations of said defendant's plant and works. He shall be given by it at all times free and full access to its books, records and premises, and during the next six months he shall make frequent and careful observations—at least one each fortnight—of the conditions of the plant and works, the manner of their operation, the quantity and character of smoke emitted therefrom, and the resulting effect upon vegetation within the vicinity and in the State of Georgia. At the end of that time he shall make a full report of his observations, accom-

[illegible]